UNIVERSITY OF ILLINOIS BULLETIN

ISSUED WEEKLY

Vol. XXVIII February 3, 1931 No. 23

[Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Acceptance for mailing at the special rate of postage provided for in section 1103, Act of October 3, 1917, authorized July 31, 1918.]

TESTS OF A MIKADO-TYPE LOCOMOTIVE EQUIPPED WITH NICHOLSON THERMIC SYPHONS

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

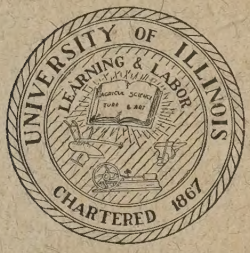
THE ILLINOIS CENTRAL RAILROAD COMPANY

AND

THE LOCOMOTIVE FIREBOX COMPANY

BY

EDWARD C. SCHMIDT
EVERETT G. YOUNG
HERMAN J. SCHRADER



BULLETIN No. 220
ENGINEERING EXPERIMENT STATION
PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

PRICE: FIFTY-FIVE CENTS

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TESTS OF A MIKADO-TYPE LOCOMOTIVE EQUIPPED WITH NICHOLSON THERMIC SYPHONS

I. Introduction

1. *The Thermic Syphon.*—The Nicholson Thermic Syphon has been generally available since 1918, and about 12 600 syphons are now in service on American and Canadian locomotives. Although in this interval the syphon has been subjected to numerous tests in road service, the results presented in this bulletin constitute the first published record of tests of this device in a locomotive testing plant, where the conditions of operation can be fully controlled.

The syphon is illustrated and described in the body of the bulletin on pages 13 to 15. It is sufficient here to describe it roughly as a water-leg of triangular longitudinal section and rectangular cross-section, terminating at the bottom in a cylindrical neck. This neck is connected to the throat sheet of the boiler, while the long and narrow upper end is connected to the crown sheet. One or more syphons are thus applied in the firebox, depending upon its size; and in locomotives with combustion chambers, additional smaller syphons are there applied. In the locomotive used for these tests two syphons were installed in the firebox. The function of the syphon is to stimulate and accelerate the circulation of the boiler water, the very rapid evaporation within it drawing the cooler water from the throat; at the same time it provides additional and highly effective heating surface.

2. *Purpose of the Investigation.*—The chief purpose of the tests the results of which are here recorded was to measure the coal and water consumed in a modern locomotive when operated, under rigidly controlled conditions, both with and without syphons, in order to determine the magnitude of the fuel savings effected by this device. The tests were made during April, May, and June, 1930, in the Locomotive Laboratory of the University of Illinois, on a 2-8-2 type locomotive, which was tested, first without syphons, and again after they had been applied.

3. *Results of the Tests.*—Since the syphons directly affect only the boiler performance of the locomotive, the adopted criterion of performance was the evaporation per pound of dry coal. The locomo-

tive was operated at four rates of evaporation chosen to represent the ordinary range of boiler output in everyday service. At all rates of evaporation the syphon-equipped locomotive showed a definite and notable superiority over the non-syphon engine as regards both evaporation per pound of coal and boiler efficiency. The facts with respect to evaporation and efficiency are discussed in Chapter V, pages 28 to 39; and the gains in these two measures of heat transmission are summarized in Table 5 and Table 7.

The secondary results of the tests are presented in Chapter VI. Concerning them it is sufficient here to say that such factors of performance as rate of evaporation, steam pressure, steam quality, draft, speed, cut-off and back-pressure were practically the same with and without syphons. At the three higher rates of evaporation the degree of superheat in the steam was substantially the same with the syphons and without them, while at the lowest rate the non-syphon locomotive produced about twenty degrees more superheat. There were differences in the temperature of the gases at various points in their passage through the boiler, which are discussed on pages 46-49.

4. *Acknowledgments.*—This investigation was undertaken as one of the coöperative researches of the Engineering Experiment Station of the University of Illinois, in coöperation with the Illinois Central Railroad and the Locomotive Firebox Company of Chicago, which manufactures the syphon. The railroad company furnished the locomotive, and all three agencies shared in the expense of conducting the tests. The general arrangements for the tests were negotiated with Mr. F. R. Mays, General Superintendent of Motive Power of the Illinois Central Railroad, and Mr. George R. Carr, Chairman of the Board of Directors, and Mr. Walter S. Carr, President of the Firebox Company.

In accordance with the usual practice of the Experiment Station in carrying on such coöperative investigations, the general program for the research was laid down by an advisory committee composed of Mr. B. J. Feeny, representing the Railroad Company, Mr. L. R. Pyle, representing the Firebox Company, and Edward C. Schmidt, representing the Station. The members of this committee not only defined the test program, but were either present or represented in the laboratory throughout all tests. The conduct of the tests, however, the calculation and analysis of the results, and the preparation of the report were under the exclusive control of the Railway Engineering Department of the University, which acted for the Experiment Station,

and which assumes full responsibility for the validity of the tests and their results.

EVERETT G. YOUNG and HERMAN J. SCHRADER, members of the Railway Engineering Department staff, were in direct charge of the tests and of the calculation of the data. Mr. SCHRADER was in charge of the laboratory and was responsible for the conduct of the tests, while Mr. YOUNG was responsible for the collection and correlation of the data and the calculation of the results. Both have had an important share in the final analysis of the results and in the preparation of this bulletin.

As previously stated, this research has been a part of the work of the Engineering Experiment Station of the University of Illinois, of which DEAN M. S. KETCHUM is the director, and of the Department of Railway Engineering, of which EDWARD C. SCHMIDT is the head.

II. The Locomotive and the Syphons

5. *General Design and Main Dimensions.*—The locomotive used for the tests was Illinois Central Railroad engine No. 1742, of the Mikado or 2-8-2 type, built in 1915 by the Lima Locomotive Works and bearing the builder's serial number 5046. A photograph of a locomotive of identical design is reproduced in Fig. 1. Its dimensions are given in detail in Appendix A; its principal dimensons are as follows:

Total weight, in working order, lb	282 700
Weight on leading truck, lb	26 300
Weight on drivers, lb	218 300
Weight on trailing truck, lb	38 100
Cylinders (simple), diameter and stroke, in	27 x 30
Diameter of drivers (nominal), in	63
Firebox, length and width, in	120⅝ x 84
Grate area, sq. ft	70.4
Boiler pressure, lb. per sq. in	185
Rated tractive force (m.e.p. = 0.85 b.p.)	54 588

	Without Syphons	With Syphons
Volume of firebox, above grate, cu. ft	346.0	336.0
Heating surface—Area of the *fireside* surfaces of all heat-transmitting boiler parts, sq. ft.:		
Of the tubes and flues	3401.2	3401.2
Of the firebox, including syphons	235.0	305.8
Of the arch tubes	31.6	15.8
Total water-evaporating surface	3667.8	3722.8
Of the superheater	1074.4	1074.4
Total, including superheater	4742.2	4797.2

The boiler, whose general design is shown in Figs. 18 and 19 in Appendix A, is of the straight top, radial-stay type, composed of three ring courses and the back end. The steam dome is mounted over a 26-inch opening in the third course, with an auxiliary dome immediately behind it. Flexible stay-bolts are used in the throat and in the breaking zones of the back-head and sides of the firebox. The front four rows of crown stays are of the Tate expansion type, the remainder being ordinary button-head stays. The two front courses of the boiler are provided with "diamond" double-welt longitudinal seams, the inside welt being hexagonal. In the third course the longitudinal seam is combined with the dome liner. The firebox crown and side sheets are made in one piece, as is also the wrapper sheet. A "Security" brick arch is mounted on four 3-inch arch tubes. This mounting was altered when the syphons were installed. The grates are of the rocking finger type, with 12 shaking bars on each side of

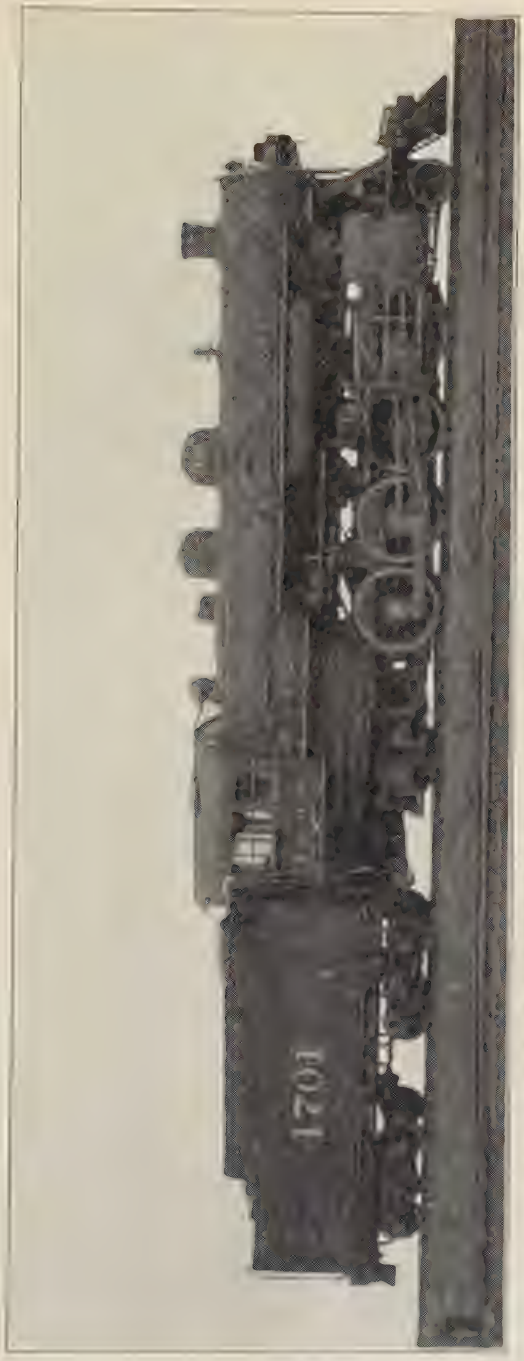


FIG. 1. AN ILLINOIS CENTRAL RAILROAD MIKADO-TYPE LOCOMOTIVE OF THE SAME DESIGN AS ENGINE NO. 1742

the center, and a pair of 13½-inch dump grates at the back. The openings in the grate amount to 25.89 sq. ft., or 36.8 per cent of the grate area. The only other air inlet to the firebox is the firedoor opening.

The boiler was provided with a Type A superheater, built by The Superheater Company, and comprising thirty-six units and a header of the through-bolt type. The average distance between the return bends and the back tube sheet was 34 inches. The superheater damper was wired in the open position during the entire time the locomotive was in the laboratory.

The front-end arrangement is shown in Fig. 18. There is no extension stack, but the petticoat pipe extends up to the level of the stack opening in the smokebox, leaving a passage of about 147 sq. in. area around the petticoat into the stack. The inside diameter of the petticoat pipe is 18⅜ inches and it flares at the bottom to a diameter of 30 inches, the bottom being 13½ inches above the top of the exhaust tip. The nozzle tip has a circular opening 6¼ inches in diameter and is provided with a ⅜-inch knife-edge bridge, the edge of which is set ¼ inch below the top of the tip. The table plate is a solid sheet; and the netting is composed of ⅛-inch wire, with openings $\frac{3}{16}$ inch by ¾ inch.

The valve gear is of the Walschaerts type, with forward motion taken from the bottom of the link, the return crank consequently lagging behind the main crank. The lap and lead lever is driven by an arm on the crosshead. Miscellaneous engine equipment included a Franklin pneumatic butterfly-type firedoor, a Ragonnet pneumatic reverse gear, Simplex injectors, and Alemite lubrication on hub liners.

6. *Condition of the Boiler and Machinery.*—During February and March, immediately preceding the tests, the locomotive had been given a general overhauling, and when received at the University it had run only 1470 miles in road service since leaving the shops. It arrived at the laboratory in excellent condition, and after being placed on the testing plant required only minor adjustments, such as guide alignment, piston-rod packing, valve setting, and the like—all of which were made by the railroad company's machinists. During the progress of the tests the engine ran the equivalent of 4235 miles. The machinery remained in excellent condition.

The boiler of the locomotive was likewise in first-class condition throughout its stay in the laboratory. The surfaces in contact with the boiler water were inspected upon arrival and were found to be

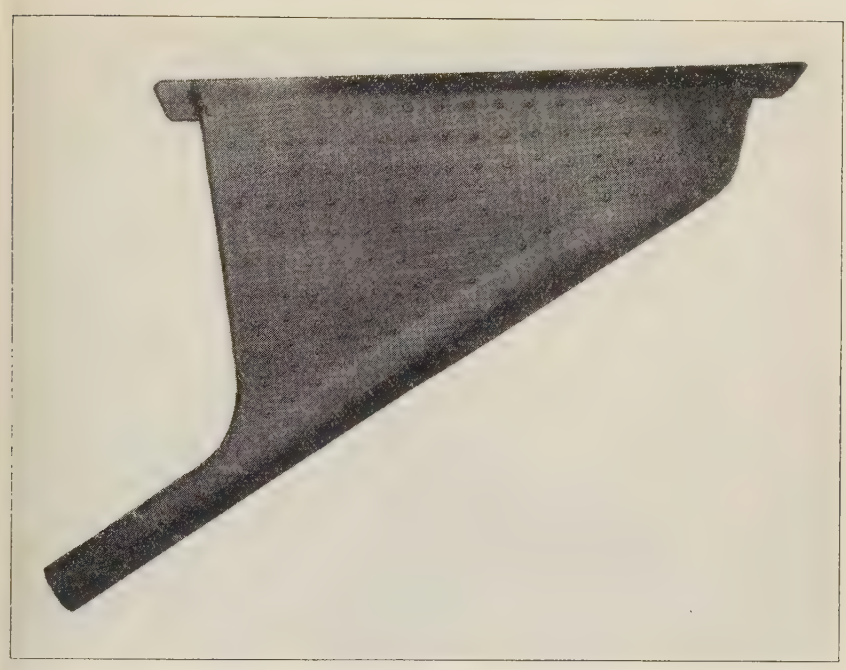


FIG. 2. REPRODUCTION OF A PHOTOGRAPH OF ONE OF THE SYPHONS INSTALLED IN LOCOMOTIVE NO. 1742

practically clean. Treated feedwater was used during the tests; and examination of the boiler surfaces at the close of the first series* of tests and again at the end of the second series showed that the only deposit during the tests was a very thin powdery white coating, which could be easily wiped off with the hand.

The boiler had been inspected when in the shops, and it was again inspected and given a hydrostatic test after the syphons were installed. It remained tight, and throughout the tests there was no leakage whatever of water or steam. The injector overflow was piped back to the laboratory feed tank; it amounted to only the initial overflow, since after beginning a test the injector setting remained practically constant, and the injectors were never started or stopped while the test was in progress.

The steaming of the engine, from the outset, indicated that the drafting arrangements were satisfactory, and no change whatever was made in the front-end after it was received at the laboratory. The

*For the sake of brevity the tests made before the syphons were applied are frequently referred to as Series I (tests Nos. 2701 to 2714 inclusive); whereas those made after the installation of the syphons are called Series II (Nos. 2715 to 2731 inclusive).

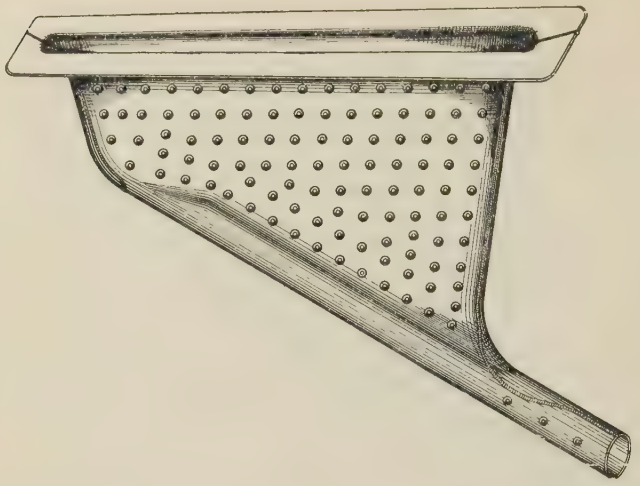


FIG. 3. A VIEW OF THE THERMIC SYPHON, SHOWING ITS GENERAL CONSTRUCTION

front-end was inspected at the beginning of the tests, during their progress, and at their conclusion; everything in it remained intact.

7. *The Syphons.*—Two syphons were installed in the locomotive before the beginning of the tests of Series II. A photograph of one of them is reproduced in Fig. 2, and a general view showing the syphon construction appears in Fig. 3. The sheets of the syphon are $\frac{3}{8}$ inch thick, and are spaced 3 inches apart; the lower bulbous portion is approximately circular in section and of $6\frac{1}{4}$ inches inside diameter. The center to center distance between the syphons is 20 inches at the front and $19\frac{3}{4}$ inches at the back, the measurements being taken along the curve of the top of the crown sheet. The syphons were installed in accordance with the latest practice, which avoids the removal of any of the fire-tubes. Two of the arch-tubes were, however, discarded and the arch, after the syphons were in place, rested upon the two remaining tubes and upon the bulbous lower portion of the syphons. The arch extended back to the same point over the grates as before the syphons were put in. Figure 4 shows the syphons in position in the firebox.

The syphons were installed by Illinois Central Railroad boiler makers under the personal supervision of the Chief Boiler Inspector. The work was done in the laboratory and without disturbing the mounting of the locomotive on the test plant. At the same time a slight play in the brasses of the right-hand main side-rod connection

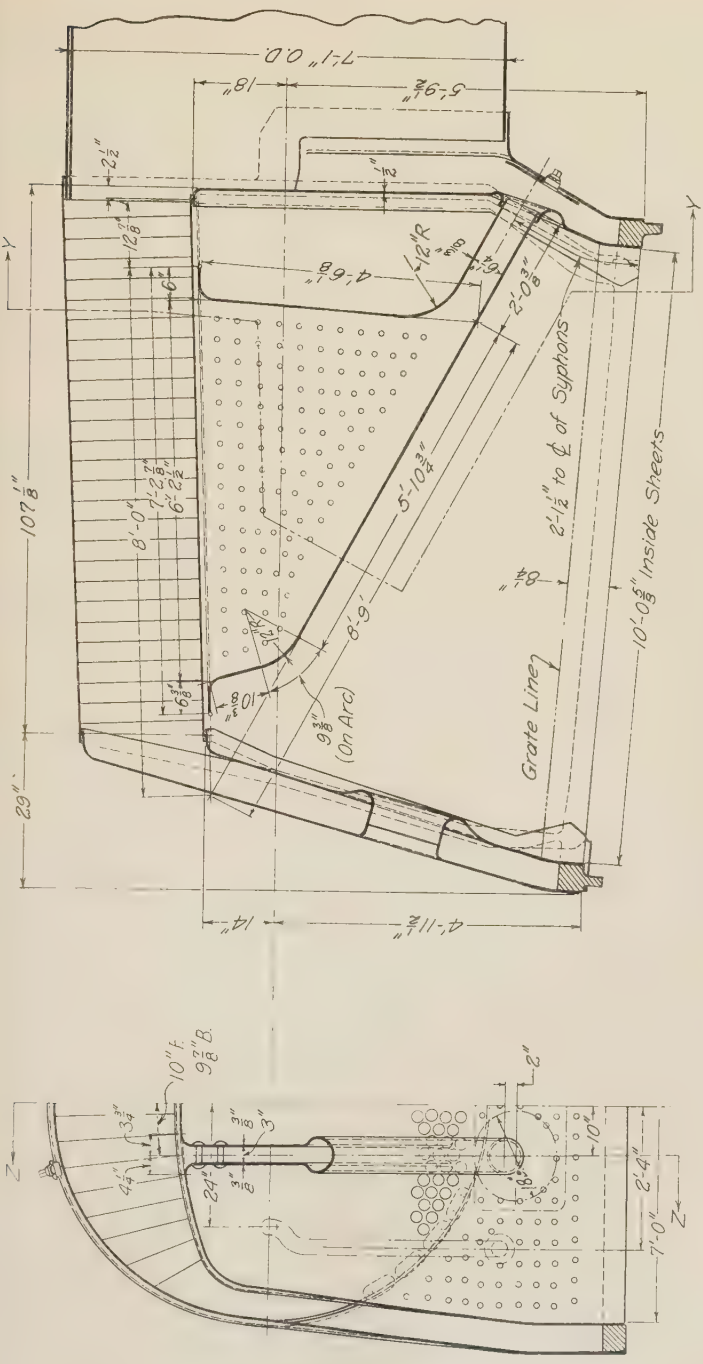


Fig. 4. The Syphons in Position in the Firebox of Engine No. 1742

was taken up; otherwise no change whatever was made in the locomotive. It is to be emphasized, therefore, that except for the installation of the syphons and the change in the firebox heating surface and volume thereby entailed, no change which could affect the performance of the locomotive was made between the tests of Series I and those of Series II.

III. The Coal Used

8. *Source, Preparation, and Composition of the Coal.*—The coal used during the tests was supplied by the Illinois Central Railroad and was produced at Mine No. 12 of the Madison Coal Corporation, located at Cambria, Williamson County, Illinois. It was run-of-mine coal passed over a two-inch screen and designated as two-inch lump coal. Twelve carloads, all mined and loaded on March 14, were shipped to Champaign and there stored within the railroad company's roundhouse, whence it was brought to the laboratory, one carload at a time, as required. Geologically, this coal is designated as "Williamson County No. 6." The mine was chosen by the General Fuel Inspector of the Illinois Central Railroad, and the coal was mined, screened, and loaded under his personal supervision—all with a view of ensuring uniformity. From its arrival in Champaign until it was fired the coal was protected from the weather, being covered by canvas in transit to the laboratory and there held under roof. It was loaded directly from the cars into the laboratory coal barrows.

Coal analyses for each test are given in Appendix D. In order to reveal the uniformity in chemical composition and heat value, there are presented in Table 1 the average percentages of each constituent for all tests, together with the maximum and the minimum percentages found by analysis for any of the tests.

In order to determine whether there was any significant variation in the size of the coal from carload to carload, a sample from each car was separated, by screening, into four parts, whose range in size is specified in the column headings of Table 2. These parts were weighed and the weights converted into percentages of the weight of the sample. The samples for this purpose were 1000-pound barrows of coal which, in regular course, would have gone to the firing platform. They were taken at a stage of unloading the car at which it was judged a characteristic sample would be obtained. The results of these screen analyses of the various carloads are presented in Table 2. Figure 5 is a reproduction of a photograph of the four parts into which the screening sample for the eighth carload was separated. The pile toward the rear is a full 1000-pound sample; the four piles in front are the constituents of a similar sample.

TABLE 1

CHEMICAL ANALYSIS AND CALORIFIC VALUE OF THE COAL

	Average Value for All Tests	Maximum Value for Any Test	Minimum Value for Any Test
Proximate Analysis of Coal, as Fired:			
Moisture, per cent	5.37	6.31	4.69
Volatile Matter, per cent	35.54	38.10	33.78
Fixed Carbon, per cent	47.22	48.96	44.61
Ash, per cent	11.87	13.38	10.34
Sulphur, separately determined, per cent	3.58	4.54	2.95
Ultimate Analysis of Coal, as Fired:			
Carbon, per cent	64.45	67.44	62.56
Hydrogen, per cent	4.86	5.27	4.41
Nitrogen, per cent	1.10	1.23	0.92
Oxygen, per cent	8.77	10.44	7.36
Calorific Value of:			
Coal, as fired, B.t.u.	11 890	12 133	11 623
Dry coal, B.t.u.	12 563	12 910	12 201

TABLE 2

SCREEN ANALYSIS OF THE COAL

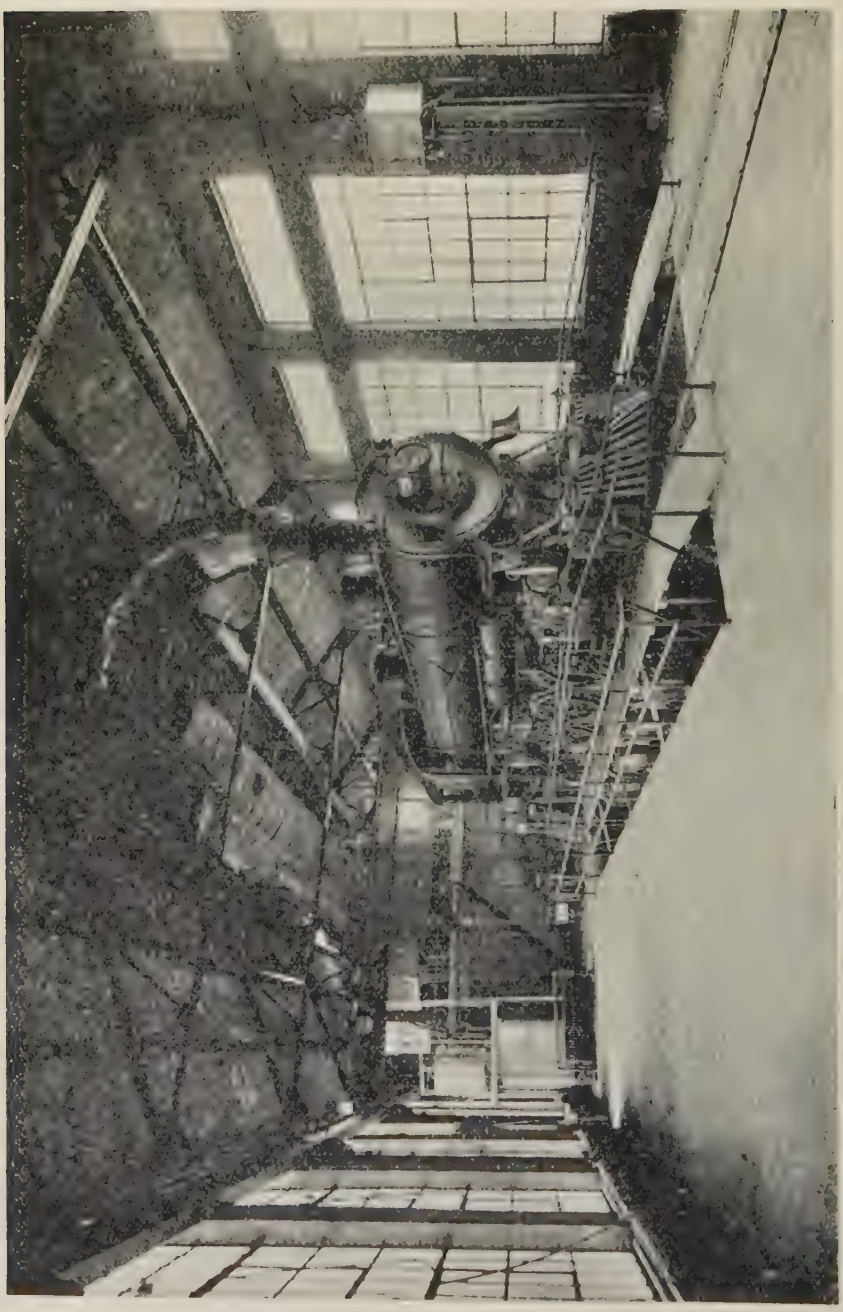
Number of the Carload	Numbers of the Tests During Which Coal from This Carload Was Used	Percentages of the Various Sizes of Which the Screening Sample Was Composed			
		Coal Passing over a 3-inch Screen	Coal Passing through a 3-inch, and over a 1-inch Screen	Coal Passing through a 1-inch, and over a ½-inch Screen	Coal Passing through a ½-inch Screen
First	2701–2704 incl.	38.3	53.3	4.3	4.1
Second	2705–2708 incl.	43.3	39.3	6.8	10.6
Third	2709–2713 incl.	31.4	49.0	9.2	10.4
Fourth	2714	39.1	45.5	7.4	8.0
Fourth*	2715–2717 incl.	22.3	46.8	12.2	18.7
Fifth	2718–2722† incl.	47.2	44.3	3.4	5.1
Sixth	2722†–2726 incl.	47.1	43.1	4.0	5.8
Seventh	2727–2730 incl.	47.6	39.9	5.4	7.1
Eighth	2731‡	34.5	51.7	6.9	6.9

*After the completion of test No. 2714 the coal remaining in the original fourth car was transferred to another car by means of a clam-shell bucket, some breakage resulting therefrom. A second screen analysis was therefore made of the transferred coal. Of the tests upon which the final conclusions are based, the only one in which this re-handled coal was used is No. 2716, which is a test at the lowest rate of evaporation used. This test was of full length and it gave results in accord with others in its group; it was agreed by all concerned that the excess fine coal resulting from the re-handling probably had had little, if any, effect at the low draft which prevailed at this low rate of evaporation. Test No. 2717, run at a higher rate of evaporation, was rejected on account of the excess of fine coal. Test No. 2715 was rejected because it had been discontinued after only 10 000 lb. of coal had been fired.

†Of the coal fired during test No. 2722, 13 000 lb. of coal were taken from the fifth carload, and 7000 lb. from the sixth.

‡Of the coal used during test No. 2731, 6000 lb. were taken from the seventh carload, 2000 lb. were a mixture of coal from the seventh and eighth cars, and 12 000 lb. were from the eighth carload.

FIG. 5. RESULTS OF ONE OF THE SCREEN ANALYSES OF THE COAL



IV. Test Program and Procedure

Only the principal facts concerning test procedure are here presented. Further explanations concerning test methods and equipment, such as the collection of stack cinders, the sampling of the coal, the measurement of temperatures, and the like, are given in Appendix B. The test methods and procedure were, in general, in accordance with the requirements of the American Society of Mechanical Engineers' Test Code for Steam Locomotives. Where it has been necessary to deviate from these requirements, that fact is specifically stated in this bulletin.

9. *General Procedure and Program.*—Under the decisions of the Advisory Committee, tests were run, in each series, at four rates of evaporation—nominally 17 500, 27 500, 37 500, and 45 000 pounds per hour (actual evaporation). These rates were chosen to represent the usual range in evaporation rate of Engine No. 1742 in road service. The test conditions were so set as to attain in Series II the same rates of evaporation as in Series I; and although this similarity was not precisely realized at all rates, the difference between the two series is small, the maximum difference in average rate being only 2.4 per cent.

The other main test conditions prescribed by the Advisory Committee were that not less than 20 000 pounds of coal be burned in each test, and that the program be continued until, in each series and at each rate of evaporation, three tests had been secured whose results should be in such close agreement as to establish a reliable average result for the rate in question. That this last purpose was attained is disclosed by consideration of the evaporation values which are presented in Chapter V. In order to avoid the disturbance arising from blowing safety valves, all tests were run at a nominal steam pressure of 182 pounds instead of at the usual working pressure of the locomotive (185 pounds).

On the assumptions that the coal used would be substantially uniform in quality throughout all tests and that the conditions of boiler operation could be maintained alike, it was agreed at the outset that the performance of the locomotive with and without syphons should be judged by comparing the evaporation and the coal consumption in the two series of tests; and that conclusions with respect to the savings effected by the syphons should rest upon a comparison of the values of equivalent evaporation per pound of dry coal—equivalent evapora-

TABLE 3
DURATION OF THE TESTS AND AMOUNT OF COAL FIRED

Series I—Without Syphons			Series II—With Syphons		
Test Number	Duration of Test hr.	Coal Fired During Test lb.	Test Number	Duration of Test hr.	Coal Fired During Test lb.
2701	5.567	20 000	2715*	3.000	10 082
2702	8.033	20 000	2716	8.567	20 000
2703	8.083	20 000	2717*	5.817	20 000
2704	5.450	20 000	2718	3.100	20 000
2705	3.500	20 000	2719	8.800	20 000
2706	7.767	20 000	2720*	5.700	18 635
2707	5.400	20 000	2721	3.133	20 000
2708	3.417	20 000	2722	3.917	20 000
2709*	3.000	20 000	2723	3.850	20 000
2710	2.850	20 000	2724	8.733	20 000
2711*	2.200	15 160	2725	6.100	20 000
2712	2.850	20 000	2726*	2.800	17 700
2713	2.850	20 000	2727*	3.583	17 825
2714	3.533	20 000	2728	6.117	20 000
			2729	5.967	20 000
			2730	3.150	20 000
			2731	3.850	20 000

*These tests are excluded from those from which the final conclusions are drawn.

tion being used, instead of actual evaporation, in order to compensate for the slight variations in feedwater temperature, steam pressure, and superheat which occur from test to test.

The locomotive was first tested in the condition in which it was received at the laboratory, that is, without the syphons; and, as previously stated, these tests are designated as Series I. The tests made after the installation of the syphons are called Series II. During the entire main investigation 31 tests were run, numbered from 2701 to 2731 inclusive. Their duration and the amount of coal fired per test appear in Table 3. Seven of these 31 tests (marked with the asterisk in Table 3) failed in some respect to meet the prescribed conditions, and they are therefore not included among the tests upon which the main results and conclusions, presented in the body of the bulletin, are based. The results of these seven tests are, however, given in the general tables of results in Appendix D. Test No. 2709, which was intended to be the first test at the highest rate of evaporation, proved to have developed a rate lower than was desired; it has no counterpart in Series II, and is rejected on that account. Tests 2715 and 2717, both run at the second rate of evaporation, were fired with coal which had been transferred from the original car into another by means of a clam-shell bucket, resulting in breakage and an excess of fine coal. They are rejected because this excess, at the draft prevailing at this

rate of evaporation, was deemed likely to entail undue cinder loss. During test 2715, furthermore, only 10 082 pounds of coal were fired. On account of difficulty with supporting-wheel bearings, with the absorption brakes, or because of the failure of other laboratory equipment, five tests had to be discontinued before the specified 20 000 pounds of coal had been fired; these tests are No. 2715, previously referred to, and also Nos. 2711, 2720, 2726, and 2727. These five tests are rejected because of the shortage in coal fired, notwithstanding the fact that all except No. 2715 gave results which are in fairly close agreement with those of the accepted tests at like rates of evaporation.

There remain therefore 24 tests which comply in all respects with the requirements laid down by the Advisory Committee—twelve tests in each series; and, in each series, three tests at each rate of evaporation. The conclusions with respect to the relative performance of the locomotive with and without syphons rest exclusively upon these 24 tests, whose numbers appear in the following list:

Series I—Without Syphons				Series II—With Syphons			
First Rate	Second Rate	Third Rate	Fourth Rate	First Rate	Second Rate	Third Rate	Fourth Rate
2702	2701	2705	2710	2716	2725	2722	2718
2703	2704	2708	2712	2719	2728	2723	2721
2706	2707	2714	2713	2724	2729	2731	2730

One supplementary test, with a special purpose, was made after the conclusion of the main investigation. This is called test No. 2732 and is referred to in Chapter VI and in Appendix C.

10. *Firing and Handling the Coal.*—During all tests the locomotive was hand-fired by the so-called "level firing" method. The fireman, Mr. Kelly Taylor, was chosen for the laboratory work by Mr. B. J. Feeny. Mr. Taylor is one of the regular firemen on the Illinois Division of the Illinois Central Railroad, has been eighteen years in service and stands near the head of the list for promotion to engineman. Although he had not previously fired in the test plant, he readily adapted himself to laboratory conditions, and his capability and skill were constantly evident. The fireman's performance having been established in preliminary runs to the satisfaction of the Advisory Committee, he was thereafter free from interference; his work, however, was under constant observation and, at the conclusion of each test, was agreed to by Messrs. Feeny and Pyle as having been satisfactory to them.

The firing was of quite unusual uniformity and regularity, as is

evidenced by the very narrow range within which the time required to burn ten tons of coal varied in successive tests at each rate of running. The most striking example of this regularity is afforded by the three tests run without syphons at the highest rate of evaporation (tests 2710, 2712, and 2713). These tests each lasted 2.85 hours, the variation between them being less than one minute. Among the three corresponding tests with the syphons the maximum difference in duration was 3 minutes. Among the tests at the lowest rate of evaporation, which lasted about eight hours, the maximum difference in duration was 19 minutes for the tests of Series I, and 14 minutes for those of Series II. For the two intermediate rates these differences lie between those just cited.

The coal was received in side-dump cars which were discharged upon a concrete pavement. It was shovelled from this pavement into the laboratory barrows, each holding about a thousand pounds; the largest lumps, such as are ordinarily broken on the engine deck, being broken down at this time. The barrow was then taken to the weighing scales, where the load was adjusted to exactly 1000 pounds; and from there it was elevated to the firing platform. During the firing-up period, coal was dumped upon the firing platform as was convenient, and during the last few minutes before the beginning of the test proper, the coal on the platform was reduced to an amount that could quickly be removed. It was so removed immediately before the beginning of the test, and, at the signal for the start, the first barrow of test coal was dumped upon the thoroughly clean platform. Thereafter coal was dumped as each barrowload was used up and the platform cleaned. If it became necessary to stop a test before firing the entire ten tons, the coal remaining on the platform at the time of the stop was shovelled back into the barrow and weighed; otherwise the last shovelful fired was the sweepings from the platform after the twentieth barrowload was used up. During the progress of the test a coal-passer on the platform kept the coal pushed over to the right side of the fireman, within convenient reach; his operations were thus better facilitated than they would ordinarily be in road service.

11. *Starting and Stopping the Tests.*—For all tests the fire was built up from a clean grate, the time until full boiler pressure was attained averaging about three hours. After the steam pressure had been built up, the locomotive was run through a period varying, from test to test, from fifteen minutes to half an hour, while the speed and

load required for the desired evaporation rate were being established. Thereafter the locomotive was run for a further period of fifteen minutes or longer in order to establish the final setting of the injector, to obtain the desired water level in the boiler, and to ensure that all other conditions of operation were steady; thereupon the test was started.

At the start the fire was, on the average, about six inches thick; in a few instances, due to delay in starting, it was a little thicker. In paragraph 30 of the A.S.M.E. Test Code it is implied that the firebed ought to be so manipulated as to have at the end of the test about the same thickness as at the beginning. Such manipulation proved to be impracticable in these tests, for the shaking of the grates entailed by this requirement would have disturbed the condition of the fire and would have thrown a large amount of combustible into the ash-pan. The shaking of the grates, therefore, was left to the judgment of the fireman, and in all tests the firebed increased in thickness, as the test progressed, by eleven or twelve inches, the thickness at the end varying from 17 to 19 inches, in most instances. The fire was maintained as nearly level as practicable during the progress of the tests, and in almost all tests it was level at the beginning and at the end.

All tests in which the full ten tons of coal were fired were stopped as follows: When the last few shovelfuls of the twentieth barrow-load were about to be fired, a representative of the University, together with Mr. Feeny and Mr. Pyle, took position to observe the steam gauge. The steam pressure was noted at the moment the last shovelful was fired. As the firing ceased the pressure soon began to fall; and when the three observers agreed that it had fallen to 2 pounds less than the pressure first noted, the test was declared closed, and the time recorded. The interval between firing the last shovelful and the end of the test varied, from test to test, from ½ minute to 2½ minutes, depending chiefly upon the rate of evaporation. The five tests in which less than ten tons of coal were fired were all stopped without warning, because of emergencies. In these tests all final observations were made as promptly as possible after the stop.

12. *Boiler Feeding.*—Before beginning the regular tests the locomotive had been run enough to establish the fact that, at the lower rates of evaporation desired, the usual injector equipment—two Simplex No. 11 injectors—could be used only by shutting off the injector several times in the course of the tests. A No. 10 injector was con-

sequently substituted on the left side; this, at a low rate of discharge, provided the 16 500 pounds of water needed at the lowest rate of evaporation, and was adequate at the second rate. For the third and fourth rates the remaining No. 11 injector proved suitable. In all tests the operation of the injector was continuous and uniform, and the required rates of delivery were so nearly attained that the greatest variation in height of water in the gauge-glass between the beginning and the end of the test was 2¾ inches. In several tests the height was the same at the end as at the beginning.

13. *Control of Speed and Cut-off.*—The speed of the engine was controlled by controlling the water-pressure within the absorption brakes. It was at all times maintained nearly constant and close to the rate desired in the various tests. Among all the tests the greatest variation of the average speed for the test from the desired speed is 0.45 r.p.m. in 120, or ⅜ of one per cent; and for 26 out of 31 tests this variation is less than $\frac{1}{10}$ of one per cent. Variations in speed, from time to time, within the tests were no greater than those just cited.

Constant cut-off during any test was ensured by fixing the position of the crosshead of the power reverse gear. Three steel bars were prepared, of varying lengths, based upon the nominal cut-offs as determined by analysis of the valve gear drawings. These lengths were checked by trial on the locomotive and found to be suitable. For any of the three desired cut-offs, one of these bars was placed between the head of the cylinder of the reverse gear and the crosshead, and the latter was then drawn tightly against the bar by means of air pressure. Thus set, the cross head was fixed in position by two set screws bearing upon the guide. Among tests of like nominal cut-off there was no difference in cut-off except that occasioned by wear of the pins in the valve gear and by variation in distortion of the gear due to variation in speed.

14. *Weighing the Coal and the Water.*—The coal scale is permanently set at a point in the route of the coal barrows to the firing platform. The poise on the tare beam of this scale was set to balance the weights of the empty barrows, which had been equalized before the tests began. The net-weight beam was kept constantly weighted for 1000 pounds; and in passing over the scale a small amount of coal was added to or taken from the barrowload to bring its weight to exactly this amount. These scales, and those for weighing the feed-

water also, were calibrated frequently during the progress of the tests. Such errors as were found, although invariably insignificant in amount, were compensated by resetting the poise on the tare beams. The observer responsible for the coal weighing kept a record of weights and the time of dumping each barrowload upon the firing platform. His records were subjected to various checks. Several observers kept a record of the time required to fire each barrowload and of the accumulated time for all loads; the coal-passer chalked up in a conspicuous place the serial number of the barrowload then in process of being fired; and the shovellers loading the barrows at the car kept a separate barrow tally.

The boiler feedwater was weighed in two tanks, each holding a maximum of about 2200 pounds, and so arranged that one tank was emptying into the main feed tank while the other was being filled from the feedwater supply line. The weighing tanks were mounted on separate scales, each of which had a tare beam upon which the weight of the empty tank could be balanced. The water in the main feed tank was kept at nearly constant level so that the injectors should work against practically constant head. The observer responsible for weighing the water kept a record of the net weight and the time of emptying each tank. Since the water was fed to the locomotive at constant rate, the failure to record two tankfuls of water would have been immediately obvious—failure to record one would have been impossible, on account of the alternation of the process.

V. Main Results of the Tests

Only the chief measures of boiler performance, namely, evaporation per pound of coal and boiler efficiency, are here presented. These results are derived from the 24 accepted tests cited on page 22. Other elements of performance are given in Chapter VI.

15. *Equivalent Evaporation.*—Table 4 shows the values of equivalent evaporation per pound of dry coal for each of the tests, and also its average value for the three tests run at each of the four evaporation rates, in each series. These values are plotted in Fig. 7, where the upper curve shows the results for the tests of Series I, without the syphons; while the curve in the center of this figure gives the results for Series II, with the syphons. The circles plotted in Fig. 7 represent the values for the individual tests,* whereas the round spots represent, for each of the four rates of evaporation, the *average* evaporation per pound of coal at the *average* rate of evaporation. The curves drawn in this figure are made to pass through these spots representing the average values, and they are accepted as defining the test performance of the boiler without and with syphons, respectively. In order to facilitate comparison, these curves and the plotted average values are duplicated and brought together at the bottom of Fig. 7.

As is always the case in a locomotive, the equivalent evaporation per pound of coal falls off, in general, as the rate of evaporation increases, due to the decrease in boiler efficiency which accompanies higher rates of evaporation and combustion. Because of this decrease, and because the evaporation rates for the two series of tests are not precisely alike, the average values plotted in Fig. 7 are not directly comparable. Considering, for example, the third rate of hourly evaporation as exhibited in Table 4 and at the bottom of Fig. 7, we find that without syphons, the average evaporation per pound of coal was 8.79 pounds and the average hourly evaporation was 47 572 pounds; whereas with the syphons, the evaporation per pound of coal was 9.55 pounds and the hourly evaporation, 46 664 pounds. In order to compare these values of evaporation per pound of coal they must be adjusted to what they would have been at some common hourly rate of evaporation. The common hourly rate chosen for this adjustment

*The numbers affixed to these circles are the last one or two numerals of the test numbers.

TABLE 4
BOILER PERFORMANCE—MAIN RESULTS

Series	Evaporation Rate	Test Number	Test Conditions (Nominal)		Dry Coal Burned per Hour	Equivalent Evaporation per Hour	Equivalent Evaporation per Pound of Dry Coal	Boiler Efficiency
			Speed, R.P.M.	Cut-off, Per Cent	Pounds	Pounds	Pounds	Per Cent
Series I Without Syphons	First	2702	80	25	2351	21 809	9.28	70.14
		2703			2335	21 277	9.11	68.77
		2706			2416	21 737	9.00	68.65
		Averages			2367	21 608	9.13	69.19
	Second	2701	120	30	3369	31 334	9.30	71.73
		2704			3461	32 232	9.31	71 06
		2707			3513	31 604	9.00	69.50
		Averages			3448	31 723	9.20	70.76
	Third	2705	120	45	5382	46 924	8.72	67.62
		2708			5484	47 857	8.73	65.59
		2714			5381	47 935	8.91	69.72
		Averages			5416	47 572	8.79	67.64
	Fourth	2710	180	45	6650	57 253	8.61	67.26
		2712			6676	55 912	8.38	65.76
		2713			6685	56 107	8.39	66.74
		Averages			6670	56 424	8.46	66.59
Series II With Syphons	First	2716	80	25	2209	21 577	9.77	76.93
		2719			2161	21 573	9.98	78.13
		2724			2176	21 532	9.90	77.80
		Averages			2182	21 561	9.88	77.62
	Second	2725	120	30	3120	31 027	9.94	76.26
		2728			3079	30 860	10.02	76.55
		2729			3174	31 006	9.77	75.51
		Averages			3124	30 964	9.91	76.11
	Third	2722	120	45	4832	46 947	9.72	75.61
		2723			4915	46 870	9.54	73.26
		2731			4925	46 175	9.38	73.47
		Averages			4891	46 664	9.55	74.11
	Fourth	2718	180	45	6121	54 796	8.95	70.10
		2721			6046	55 634	9.20	70.46
		2730			6007	54 743	9.11	69.23
		Averages			6058	55 058	9.09	69.93

is the mean of the actual hourly rates, and in this instance this rate is $(47\ 572 + 46\ 664) \div 2 = 47\ 118$ pounds per hour. This mean rate is represented in Fig. 7 by the vertical line *c*. In other words, in order to determine the relative standing of the non-syphon and the syphon-equipped locomotive we must resort to the *curves* of Fig. 7 instead of to the direct test averages; and, for the third rate of evaporation, use values of evaporation per pound of coal derived from the curves at the hourly rate represented by the line *c*. At the point where the curve for Series I intersects the line *c* the equivalent evaporation per pound of dry coal amounts to 8.80 pounds; and the curve for Series II cuts this line at a point representing 9.53 pounds of equivalent evaporation. These two values—8.80 and 9.53—apply to a common hourly rate (47 118 pounds) and they are, consequently, directly

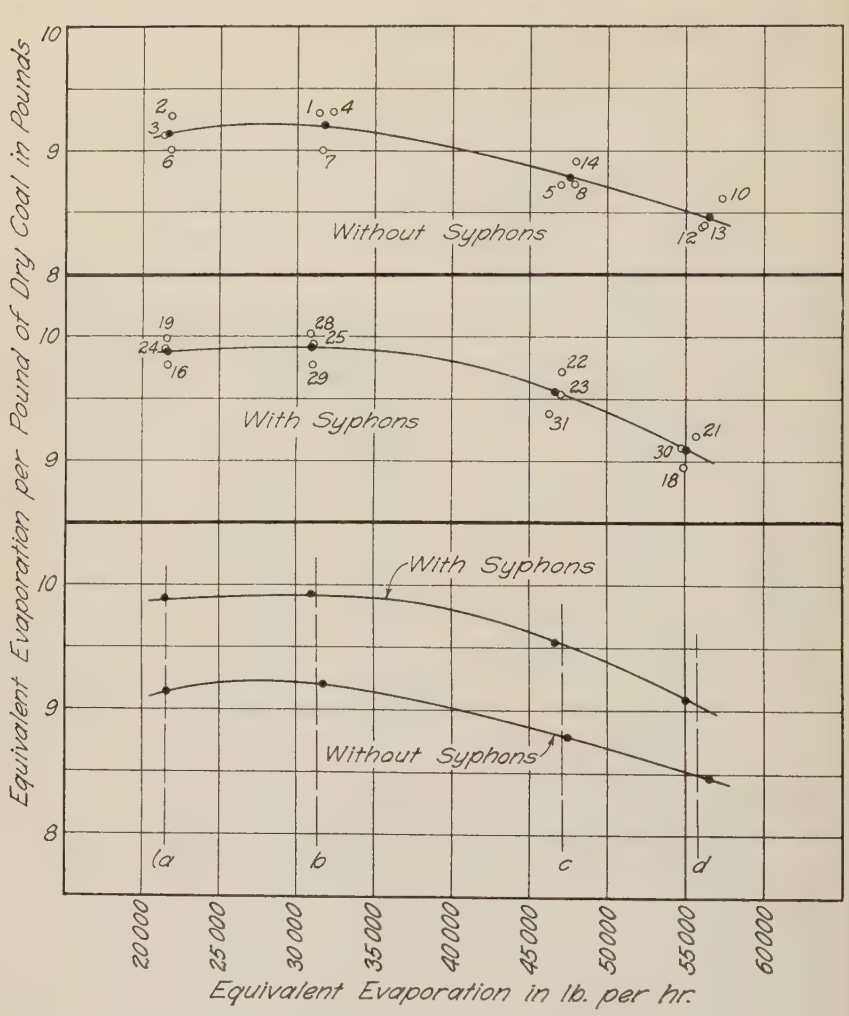


FIG. 7. CURVES OF EQUIVALENT EVAPORATION PER POUND OF DRY COAL, AT VARIOUS RATES OF EVAPORATION

To facilitate comparison, each of the two upper curves in this figure is duplicated in the lower pair, which are plotted on a common system of coördinates.

comparable. They are accepted as defining the evaporative performance of the boiler without and with syphons, respectively, at the third rate of evaporation. The gain in evaporation effected by the syphons at this rate is, therefore, $9.53 - 8.80 = 0.73$ pounds; and the percentage gain is $(0.73 \div 8.80) \times 100 = 8.30$ per cent. The average test results for the three other rates of evaporation have been simi-

TABLE 5
EQUIVALENT EVAPORATION PER POUND OF COAL, ADJUSTED TO A COMMON EVAPORATION RATE

Evaporation Rate	Equivalent Evaporation per Hour	Equivalent Evaporation per Pound of Dry Coal		Increase in the Equivalent Evaporation per Pound of Dry Coal Due to Syphons		
		Series I Without Syphons	Series II With Syphons	Pounds (Col. 4– Col. 3)	Per Cent (Based on Col. 3)	
	Pounds	Pounds	Pounds			
1	2	3	4	5	6	7
First	21 608	9.13				
	21 561		9.88			
	Mean (line a) 21 585	9.13	9.88	0.75	8.21	
Second	31 723	9.20				
	30 964		9.91			Average for All Four Rates 7.74
	Mean (line b) 31 344	9.20	9.91	0.71	7.72	
Third	47 572	8.79				
	46 664		9.55			
	Mean (line c) 47 118	8.80	9.53	0.73	8.30	
Fourth	56 424	8.46				
	55 058		9.09			
	Mean (line d) 55 741	8.48	9.05	0.57	6.72	

larly adjusted, and the test averages together with the final adjusted values are assembled in Table 5. It is to be noted that the adjusted values for the first and second evaporation rates given in this table are the same as the actual average test results. This is merely because the adjustments are so small as to be negligible, due to the facts that the differences between the actual hourly rates of evaporation for the two series are very small, and that the curves in Fig. 7, where they intersect the lines *a* and *b*, are nearly horizontal.

In column 5 of Table 5 are shown the increases in evaporation per pound of dry coal effected by the syphons at each of the four hourly rates of evaporation; and column 6 shows these increases expressed as a percentage of the evaporation secured without the syphons. The general average increase, combining all four rates, appears in column 7. These three columns of Table 5 consequently embody the main results of the whole investigation, which may be summarized as follows:

Rate of Equivalent Evaporation per Hour	Increase in Equivalent Evaporation per Pound of Dry Coal Effected by the Syphons
First, 21 585 lb	8.21 per cent
Second, 31 344 lb	7.72 per cent
Third, 47 118 lb	8.30 per cent
Fourth, 55 741 lb	6.72 per cent
General Average Increase for All Four Rates	7.74 per cent

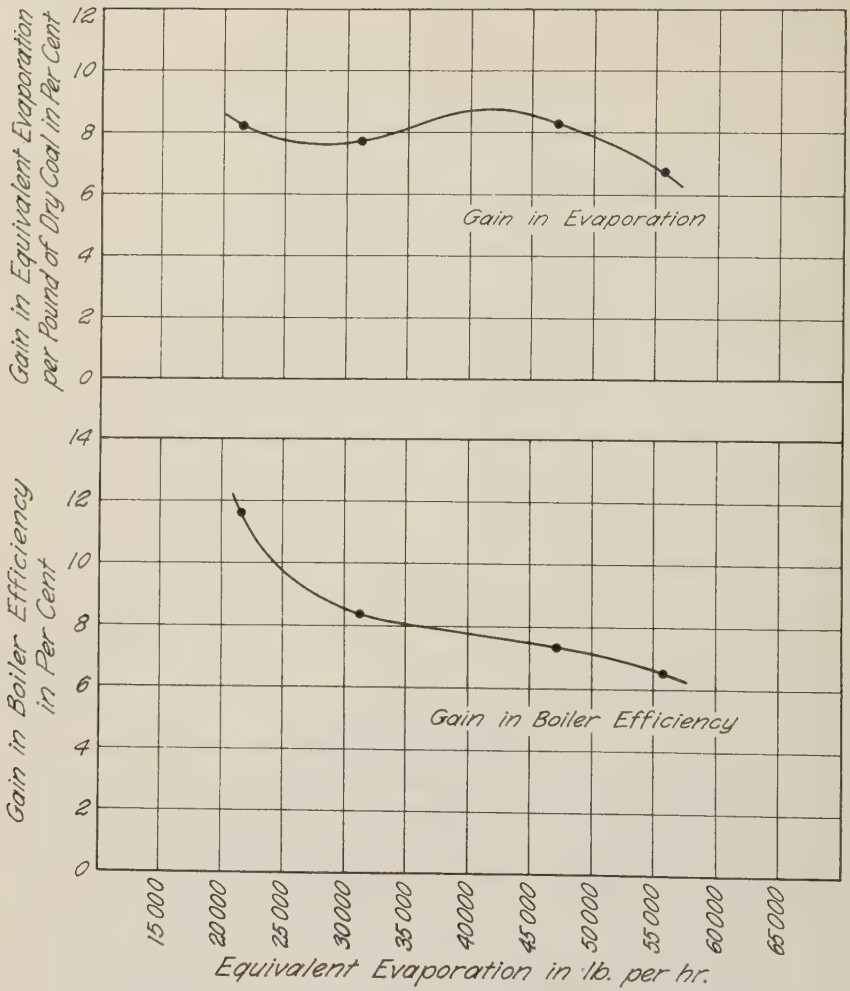


FIG. 8. CURVES SHOWING GAIN IN EVAPORATION PER POUND OF COAL AND GAIN IN BOILER EFFICIENCY, DUE TO THE SYPHONS

These results show that under the conditions which prevailed during the tests, locomotive No. 1742 generated 8.21, 7.72, 8.30, or 6.72 per cent more steam per pound of dry coal when equipped with syphons, than when not so equipped—at the respective hourly rates of evaporation here shown. These percentage increases are plotted in the upper part of Fig. 8 in order to show the relation between the gain in evaporation and the hourly rate of evaporation.

The general test conditions have been explained in Chapter IV and the specific conditions are exhibited in detail in Chapter VI. In discussing these main results of the tests it is pertinent, however, to re-emphasize the fact that among the tests of Series I and Series II there was unusual uniformity of operating conditions. Although, as previously stated, the use of equivalent evaporation as the criterion of performance compensates for such differences in feedwater temperature, steam pressure, steam quality, and superheat as did exist between the two series, it is proper to point out—since it is a fact of practical importance—that the degree of superheat attained with and without the syphons was substantially the same at the three high rates of evaporation; and that at the lowest rate the average superheat with the syphons was only 20 degrees less than without them.

The four rates of evaporation used during the tests were so chosen as to represent the ordinary range in evaporation rate for this engine in daily service, and the rates attained do fairly represent the service range. The average maximum rate for each of the two series of tests was as follows:

	Series I Without Syphons	Series II With Syphons
Actual Evaporation, lb. per hr	41 956	40 872
Equivalent Evaporation, lb. per hr	56 424	55 058

It is not likely that a locomotive of this type and size would be worked at a higher rate than this, except for occasional and very short periods. In attempting to predict from the test results what gain would accrue from the use of syphons in the daily road operation of such a locomotive, it must be borne in mind that the test results at the four rates of evaporation are not equally significant, and that the *average* performance on the road would not necessarily be the same as the general average test performance; because in road service some one or two rates of evaporation may preponderate over the others. Under the modern striving for maximum ton-miles-per-hour output, it is likely that such a locomotive would, on the road, operate for longer periods at the higher rates of evaporation—the prevailing rate depending, of course, upon the operating policy, the conditions of traffic, and the road profile. If, under the conditions existing in a given case, the third test rate should predominate, the average daily gain in evaporation per pound of coal effected by the syphons would be somewhat greater than the general average gain of 7.74 per cent shown during the tests.

As will later appear from the discussion in Chapter VI and in Appendix C, the syphon is especially advantageous during the period

of building up the fire and attaining full steam pressure; and this advantage repeats its influence after each stop of considerable length. During the tests, however, the engine was run continuously and in them, consequently, this advantage could make itself felt only once. If, therefore, the conditions of road service are such as to entail frequent stops of considerable duration, it may be expected that the gains effected by the syphons at all rates of evaporation will be greater than the gains shown during the tests.

16. *Boiler Efficiency.*—The values of boiler efficiency* attained during each test, and also of the average efficiency for the three tests run at each of the four evaporation rates, in each series, appear in the last column of Table 4. The corresponding hourly rates of evaporation are shown in the seventh column. These values are plotted in the upper part of Fig. 9, where (as in Fig. 7) the circles represent the efficiency values for individual tests, while the round spots represent, for each of the four rates of evaporation, the average result at the average hourly evaporation rate.

For convenience in comparing them, these average values are assembled in Table 6, which shows, therefore, for each evaporation rate in each series, the direct results of the tests. From column 4 of Table 6 it appears that without the syphons the average efficiency was 69.19, 70.76, 67.64, and 66.59 per cent at the respective evaporation rates; whereas with the syphons the corresponding efficiency values are 77.62, 76.11, 74.11, and 69.93 per cent. At all rates of evaporation therefore the syphon-equipped boiler operated at higher efficiency, by amounts which appear in column 5. When these amounts are expressed as percentages of the respective efficiency values attained without the syphons, we find that the increase in efficiency due to syphons is 12.18, 7.56, 9.57, and 5.02 per cent at the first, second, third, and fourth rates of evaporation, respectively. These percentage increases are shown in column 6.

If the quality of the coal had been the same throughout, and if in each group the rates of evaporation had been exactly the same in both series of tests, we would expect—in view of the uniformity of other test conditions—that these increases in efficiency would be nearly the same as the increases in evaporation per pound of dry coal discussed at the beginning of this chapter. This, however, is not the case. In order to facilitate comparison these percentage increases in

*Boiler efficiency here has its usual significance; namely, the ratio of the heat units transmitted to the steam to the heat units in the coal fired.

TABLE 6

BOILER EFFICIENCY, BASED UPON THE AVERAGE DIRECT RESULTS OF THE TESTS

Evaporation Rate	With or Without Syphons	Equivalent Evaporation per Hour	Average Boiler Efficiency	Difference in Efficiency	Percentage Gain in Efficiency Due to Syphons, Based on Series I	Percentage Gain in Evaporation. Adjusted Values from Table 5	Average Heating Value of the Dry Coal B.t.u. per Pound	
		Pounds	Per Cent	Per Cent			For Each Series	Difference between Series
1	2	3	4	5	6	7	8	9
First	Without	21 608	69.19	8.43	12.18	8.21	12 802	452 more without syphons
	With	21 561	77.62				12 350	
Second	Without	31 723	70.76	5.35	7.56	7.72	12 616	18 more with syphons
	With	30 964	76.11				12 634	
Third	Without	47 572	67.64	6.47	9.57	8.30	12 605	114 more without syphons
	With	46 664	74.11				12 491	
Fourth	Without	56 424	66.59	3.34	5.02	72	12 325	285 more with syphons
	With	55 058	69.93				12 610	
All Rates	Without	General Average Values for All Four Rates of Evaporation.			8.58	7.74	12 587	66 more without syphons
	With						12 521	

evaporation per pound of coal are repeated in column 7 of Table 6; and, for the same purpose, the average heating value of the coal and the differences in heating value for the two series of tests are presented in columns 8 and 9. Comparing columns 6 and 7, it is apparent that the gain in efficiency and the gain in evaporation are not alike at any of the evaporation rates; the most notable difference occurring at the lowest rate, where the gain in efficiency is 12.18 per cent, whereas the gain in evaporation per pound of coal is 8.21 per cent. This difference is doubtless due in large measure to the difference which existed, at this rate of evaporation, between the heating values of the coal with and without syphons, and which amounts to 452 B.t.u. At this rate the syphon-equipped locomotive generated 8.21 per cent more steam per pound of dry coal than the non-syphon locomotive, notwithstanding the fact that the heating value of the coal supplied to it was inferior by 452 B.t.u. Since in this instance the evaporation rates for the two series are almost identical (21 608 and 21 561 pounds per hour), the influence of rate of evaporation upon efficiency is obviously not responsible for the difference under discussion, and this difference must be attributed largely to the variation in quality of the coal. The inference is unescapable that had the syphon-equipped locomotive not happened to be furnished, at the

lowest evaporation rate, with coal of somewhat inferior quality, its gain in evaporation per pound of coal would have been, not 8.21 per cent, but considerably more.

The differences between gain in efficiency and gain in evaporation per pound of coal are not so great at the three higher rates of evaporation as at the first rate; but they are all in the direction which would be anticipated from the differences in heating value exhibited in column 9 of Table 6. They are, no doubt, to be accounted for in large measure by the variation in quality of the coal. Variations in rate of evaporation, in themselves, however, influence efficiency; and since at these three rates the evaporations per hour are not precisely alike, it is impossible to say what share of the difference in gains should be attributed to variations in the coal and what share to variations in rate of evaporation. In this connection it should be pointed out that we have been comparing gains in efficiency based on the direct average test results unadjusted for differences in rate of evaporation, with gains in evaporation per pound of coal based upon values of evaporation which have been adjusted to a common evaporation rate.

17. *Adjusted Values of Efficiency.*—At each of the four nominal test rates, the actual average evaporation per hour with the syphons was a little less than the average evaporation without syphons—as has already been pointed out in discussing the evaporation results. The difference is not great, the maximum variation being only 1366 pounds per hour, in some 56 000 pounds—at the fourth rate. This amounts to only 2.4 per cent. Since in a locomotive the efficiency is generally greater as the rate of evaporation decreases, the syphon-equipped engine is at a slight advantage, as regards efficiency, because of the differences in evaporation rate just referred to; and although this advantage is slight, it is nevertheless necessary to adjust the direct efficiency results of the tests to a common rate of evaporation before they may be properly compared. This adjustment—as in adjusting the evaporation results—can be accomplished only by drawing among the plotted average values of efficiency in Fig. 9. a curve for each test series which will represent the relation between efficiency and rate of evaporation which exists among the test results. In this instance, however, the drawing of these curves is not so simple a matter as it was in Fig. 7. The four plotted averages for each series shown in Fig. 9 are so related that it is impossible to draw through them a curve of single curvature; and it is necessary therefore, in

drawing the curve, to pass it as close as may be to the plotted average values and still maintain the general curvature and trend which we know such an efficiency curve must have. The curves shown in Fig. 9 are thus drawn. The curve for the tests without the syphons passes directly through the points representing the average results at the first and second rates; at the third rate the ordinate of the curve is 0.6 per cent greater than the test average, while at the fourth rate the curve ordinate is 0.5 per cent less. The curve drawn for the tests with the syphons misses all four of the plotted points, and its ordinates differ from the average test results by -0.6, $+0.8$, -0.9, and $+1.2$ per cent, at the respective evaporation rates. These deviations are so small that it is believed that the curves drawn in Fig. 9 represent at least as truly the general relation actually existing in the two series of tests between efficiency and rate of evaporation as would curves of double curvature forced exactly through the plotted averages, but whose shape would be at variance with common experience.

The curves shown in the upper part of Fig. 9 are accepted therefore as representing for these tests the relation between boiler efficiency and the hourly rate of evaporation. They are reproduced and brought together in the lower part of this figure in order that they may be more easily compared. The comparison—as in the case of evaporation per pound of coal—is made at four rates of evaporation; namely, 21 585, 31 344, 47 118, and 55 741 pounds per hour. Each of these rates is the mean between the actual average test values of the corresponding hourly rates; they are represented in Fig. 9 by the vertical lines *a*, *b*, *c*, and *d*. The values of efficiency defined by the points at which the curves of Fig. 9 intersect these vertical lines apply to a common rate of evaporation, and they are, consequently, strictly comparable. These values are shown in the third and fourth columns of Table 7, and they provide the basis upon which the superiority of the syphon-equipped locomotive, as regards boiler efficiency, may be fairly judged. At the lowest evaporation rate the efficiency values with and without syphons are respectively 77.18 and 69.15 per cent, and the difference in efficiency is 8.03. This difference constitutes 11.61 per cent of the efficiency without syphons, and this percentage is therefore the gain in efficiency effected by the syphon at the first rate of evaporation. The gains in efficiency for all four rates, thus derived, are shown in the last column of Table 7.

If we use boiler efficiency as the criterion of performance of the locomotive, the gains in heat transmission from the coal to the steam

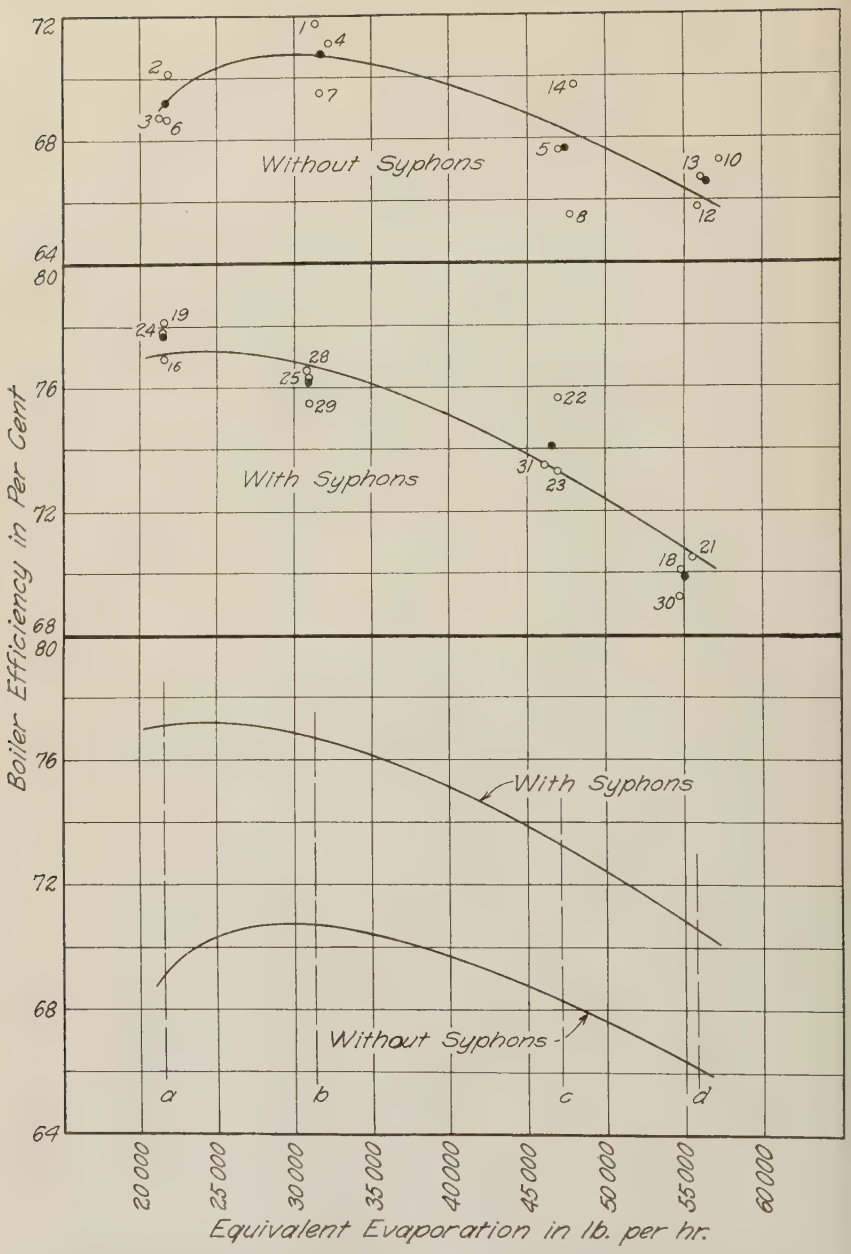


FIG. 9. CURVES OF BOILER EFFICIENCY, AT VARIOUS RATES OF EVAPORATION

To facilitate comparison, each of the two upper curves in this figure is duplicated in the lower pair, which are plotted on a common system of coördinates.

TABLE 7

BOILER EFFICIENCY—VALUES ADJUSTED TO A COMMON EVAPORATION RATE

Evaporation Rate	Equivalent Evaporation per Hour, Pounds*	Boiler Efficiency—Adjusted Values: Series I Without Syphons, Per Cent	Boiler Efficiency—Adjusted Values: Series II With Syphons, Per Cent	Difference in Efficiency between the Two Series	Increase in Efficiency Due to Syphons $\frac{\text{Col. 5}}{\text{Col. 3}} \times 100$, Per Cent
1	2	3	4	5	6
First	21 585	69.15	77.18	8.03	11.61
Second	31 344	70.78	76.71	5.93	8.38
Third	47 118	68.32	73.32	5.00	7.32
Fourth	55 741	66.23	70.58	4.35	6.57
General Average Increase in Efficiency, for All Four Rates					8.47

*The figures in this column are the mean values of the actual test rates, defined by the lines a, b, c, and d in Fig. 9.

effected by the use of syphons in locomotive No. 1742 may be summarized thus:

Rate of Equivalent Evaporation per Hour	Increase in Boiler Efficiency Effected by the Syphons
First, 21 585 lb	11.61 per cent
Second, 31 344 lb	8.38 per cent
Third, 47 118 lb	7.32 per cent
Fourth, 55 741 lb	6.57 per cent
General Average Increase for All Four Rates	8.47 per cent

These gains in efficiency, together with the gains at intermediate rates derived from the curves of Fig. 9, have been plotted to define the lower curve shown in Fig. 8, which shows the relation between gain in efficiency and hourly rate of evaporation for the entire test range.

18. *Boiler Efficiency as the Criterion of Performance.*—Equivalent evaporation per pound of dry coal, as has been stated, was chosen by the Advisory Committee as the criterion of performance for these tests; and it is a common practical standard for judging the relative performance of boilers. Its use rests upon the implied assumption that the heating value of the coal will be the same in all tests; which is rarely the case. Boiler efficiency, since it takes into account any existing difference in heating value, is a better criterion; and the real superiority of the thermic syphon, as a device for stimulating the heat transmission in a locomotive boiler, is doubtless more truly revealed by the gains in efficiency shown in Table 7 than by the gains in evaporation per pound of coal shown in Table 5.

VI. Secondary Results and Conditions of Boiler Performance

This chapter presents, for the 24 accepted tests, the secondary results of the boiler performance, such as degrees of superheat; and such conditions of performance as steam pressure. For convenience of reference most of the results are assembled in Table 8, in which are given not only the average values for each test, but the average of these average values for the three tests at like rates of evaporation in each series. Each of the last two topics herein discussed has its separate tabular presentation.

19. *Steam Pressure and Quality.*—The average values of boiler pressure appear in column 10 of Table 8. For the two series of tests they are as follows:

Rates of Evaporation	First	Second	Third	Fourth
Boiler Pressure—Series I	180.0	178.7	176.9	177.3
Boiler Pressure—Series II	183.0	182.1	181.9	180.3

The difference between Series I and II is about three pounds, except at the third rate, where it is five pounds. The maximum variation among the boiler pressures for the three tests of each group from which the averages listed are derived is also about three pounds. Such differences have little, if any, practical importance; and they have no significance in judging the superiority of the syphon as a heat-transmitting device, since the criteria for this comparison compensate for such differences in pressure as do exist.

The quality of the steam is indicated by the values in column 13 of Table 8. It is substantially the same for both series; the range in the general averages for the various rates of evaporation being from 0.974 to 0.979. The range among the 24 individual tests is from 0.969 to 0.985.

20. *Steam Temperatures and Superheat.*—The values of steam temperature and of the superheat in the steam, within the branch pipe, appear in Table 8 in columns 14 and 16, respectively; while the values of temperature and superheat* in the exhaust passage appear in col-

*While the terms "steam temperature" and "superheat" have definite meanings which are generally understood, there is occasional confusion as to their meaning and use. It seems worthwhile, therefore, here to state that "temperature of the steam" means its total temperature in the superheated state; and that "superheat" or "degree of superheat" means that excess of temperature acquired by saturated steam in passing through the superheater. The steam in the branch pipe is superheated steam; and if from its temperature we deduct its superheat (or degrees of superheat), the remainder is the temperature which saturated steam would have at branch-pipe pressure.

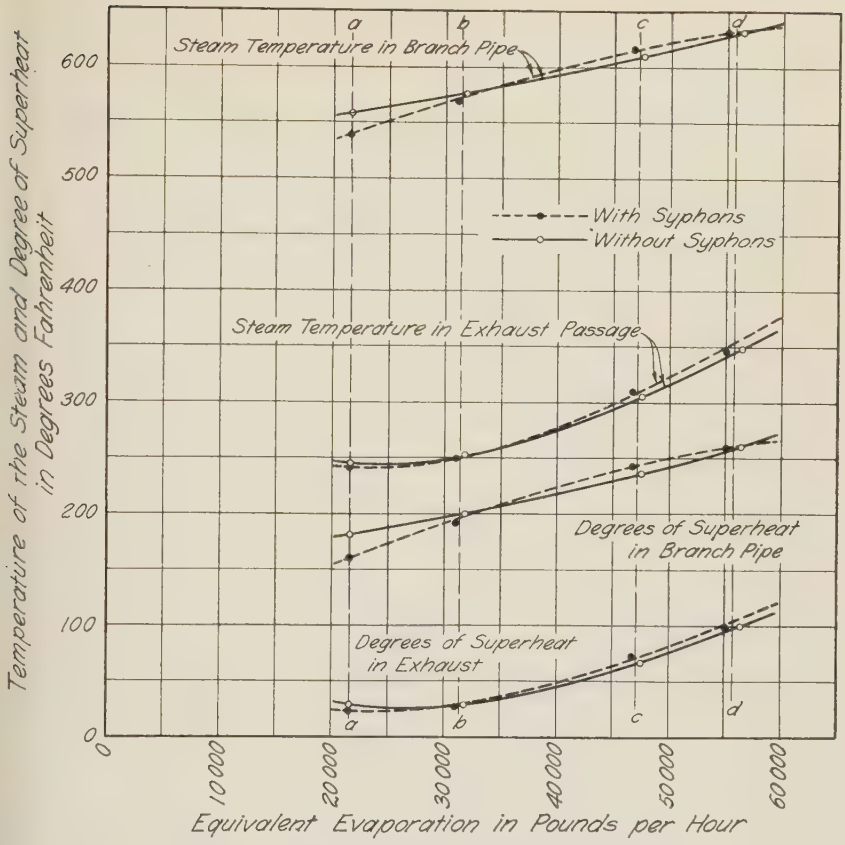


FIG. 10. STEAM TEMPERATURES AND DEGREES OF SUPERHEAT IN THE BRANCH PIPE AND IN THE EXHAUST PASSAGE

umns 15 and 17. These average values—for each rate of evaporation and in each series of tests—are plotted in Fig. 10; and the curves there drawn represent the relations between these quantities and evaporation rate. The curves drawn in full lines show these relations for the tests without syphons, while those drawn in broken lines apply to tests with the syphons.

The steam temperature and superheat in the branch pipe, for the two series of tests, may be summarized as follows:

STEAM TEMPERATURE IN BRANCH PIPE—DEG. F.

Rates of Evaporation	First	Second	Third	Fourth
Temperature Without Syphons	558.2	575.9	610.0	632.0
Temperature With Syphons	539.0	569.3	618.0	631.3
Degrees More Without Syphons	19.2	6.6	.....	0.7
Degrees More With Syphons	.....	.....	8.0	.....

Table 8

Boiler Performance—Secondary Results

General Test Conditions				Test Number	Average Actual Speed		Average Actual Cut-off	Equivalent Evaporation per Hour	Steam Pressure (Gauge), Pounds per square inch			Quality of Steam in the Dome	Steam Temperature, Degrees Fahrenheit		Degree of Superheat, Degrees Fahrenheit	
Without or With Syphons	Rate of Evaporation	Nominal Speed R.P.M.	Nominal Cut-off Per Cent		Revolutions per Minute	Miles per Hour	Per Cent	Pounds	In the Boiler	In the Branch Pipe	In the Exhaust Passage		In the Branch Pipe	In the Exhaust Passage	In the Branch Pipe	In the Exhaust Passage
Code Item Nos. ☞					107	109	219		124	125	127	179	116	117	180	181
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Series I Without Syphons	First	80	25	2702	80.04	14.34	24.7	21 809	180.4	176.0	1.12	0.9748	564.5	244.6	187.2	30.1
				2703	80.04	14.34	24.8	21 277	179.8	176.1	1.50	0.9744	561.6	247.8	184.2	31.5
				2706	80.03	14.33	24.8	21 737	179.8	178.6	1.63	0.9793	548.6	241.3	170.2	24.7
				Averages	80.04	14.34	24.8	21 608	180.0	176.9	1.42	0.9762	558.2	244.6	180.5	28.8
	Second	120	30	2701	120.45	21 57	32.0	31 334	179.6	170.8	4.50	0.9769	583.5	255.4	208.5	30.4
				2704	120.00	21.49	32.4	32 232	180.1	171.9	4.12	0.9786	572.4	250.0	196.0	25.8
				2707	120.00	21.49	29.5	31 604	176.3	171.3	3.41	0.9812	571.8	253.5	196.3	31.5
				Averages	120.15	21.52	31.3	31 723	178.7	171.3	4.01	0.9789	575.9	253.0	200.3	29.2
	Third	120	45	2705	120.05	21.50	45.9	46 924	177.9	166.9	.....	0.9784	607.0	303.0	233.3	....
				2708	119.59	21.42	46.5	47 857	176.4	166.6	10.19	0.9790	663.0	301.0	229.9	61.7
				2714	120.01	21.49	47.4	47 935	176.5	164.9	10.21	0.9768	620.0	312.7	247.2	73.4
				Averages	119.88	21.47	46.6	47 572	176.9	166.1	10.20	0.9760	610.0	305.6	236.8	67.6
	Fourth	180	45	2710	179.94	32.23	47.8	57 253	179.0	161.7	15.44	0.9774	637.0	354.0	265.7	104.2
				2712	180.04	32.25	48.0	55 912	176.4	160.9	15.27	0.9766	630.0	351.0	259.2	101.6
				2713	180.19	32.27	48.3	56 107	176.5	161.1	15.19	0.9739	629.0	343.0	258.0	93.6
				Averages	180.06	32.25	48.0	56 424	177.3	161.2	15.30	0.9760	632.0	349.3	261.0	99.8
Series II With Syphons	First	80	25	2716	80.00	14.33	24.8	21 577	182.0	176.4	2.09	0.9765	540.0	246.0	162.1	28.2
				2719	80.01	14.33	24.4	21 573	184.1	179.7	2.59	0.9734	542.0	239.0	162.6	19.0
				2724	80.00	14.33	23.8	21 532	182.8	179.2	1.67	0.9845	535.0	237.0	155.8	20.2
				Averages	80.00	14.33	24.3	21 561	183.0	178.4	2.12	0.9781	539.0	240.7	160.2	22.5
	Second	120	30	2725	120.03	21.50	30.0	31 027	182.0	175.4	3.57	0.9850	570.0	250.0	192.4	27.0
				2728	119.98	21.49	30.0	30 860	181.7	174.7	3.55	0.9763	572.0	250.0	194.8	27.2
				2729	120.01	21.49	30.3	31 006	182.6	173.6	3.63	0.9762	566.0	249.0	189.3	26.2
				Averages	120.01	21.49	30.1	30 964	182.1	174.6	3.58	0.9792	569.3	249.7	192.2	26.8
	Third	120	45	2722	120.00	21.49	47.5	46 947	182.3	168.5	9 69	0.9761	621.0	311.0	246.5	72.7
				2723	119.99	21.49	46.1	46 870	183.2	168.8	9.80	0.9694	615.0	310.0	240.4	71.5
				2731	120.26	21.54	47.6	46 175	180.3	165.5	8.02	0.9763	618.0	308.0	244.9	73.7
				Averages	120.08	21.48	47.1	46 664	181.9	167.6	9.17	0.9739	618.0	309.7	243.9	72.6
	Fourth	180	45	2718	180.03	32.24	46.4	54 796	179.1	160.4	14.71	0.9756	626.0	345.0	255.2	96.2
				2721	179.88	32.22	46.5	55 634	181.8	162.9	14.71	0.9767	638.0	349.7	266.1	101.1
				2730	179.98	32.23	45.7	54 743	180.1	160.5	13.30	0.9725	630.0	344.0	259.2	98.1

General Test Conditions				Test Number	Drafts—Inches of Water							Temperature of Gases, Deg. F.		
						In the Firebox				In Smokebox		In the Firebox		
Without or With Syphons	Rate of Evaporation	Nominal Speed R.P.M.	Nominal Cut-off Per Cent		In the Ash Pan	At Point A	At Point B	At Point C	Average for Points A, B, C	In Front of Diaphragm	Back of Diaphragm	Below the Arch	Above the Arch	In the Smokebox
Code Item Nos. ☞					132	131	131	131	131	129	130	123	123	122
1	2	3	4	5	18	19	20	21	22	23	24	25	26	27
Series I Without Syphons	First	80	25	2702	0.04	0.8	0.8	0.9	...	2.34	1.79	1960	1545	516.5
				2703	0.04	0.8	0.7	0.8	...	2.29	1.74	2017	1580	504.0
				2706	0.03	0.8	0.9	0.9	...	2.47	1.86	1892	1678	494.0
				Averages	0.04	0.8	0.8	0.9	0.8	2.37	1.80	1956	1601	504.8
	Second	120	30	2701	0.06	1.2	1.3	1.3	...	4.28	3.23	2140	1760	542.3
				2704	0.07	1.4	1.2	1.4	...	4.55	3.39	2228	1757	522.4
				2707	0.06	1.3	1.3	1.4	...	4.35	3.19	2074	1817	516.0
				Averages	0.06	1.3	1.3	1.4	1.3	4.39	3.27	2147	1778	526.9
	Third	120	45	2705	0.13	2.1	2.2	2.3	...	9.20	6.50	2167	1934	555.0
				2708	0.14	2.3	2.2	2.3	...	8.88	6.25	2182	1893	564.0
				2714	0.15	2.2	2.5	2.5	...	9.15	6.57	2060	....	562.0
				Averages	0.14	2.2	2.3	2.4	2.3	9.08	6.44	2136	1914	560.3
	Fourth	180	45	2710	0.18	2.8	2.8	2.8	...	12.03	8.34	2226	1920	584.0
				2712	0.17	2.3	2.1	3.1	...	11.48	8.16	2235	1903	583.0
				2713	0.17	2.7	2.8	3.0	...	11.60	8.12	2212	1905	575.0
				Averages	0.17	2.6	2.6	3.0	2.7	11.70	8.21	2224	1909	580.7
Series II With Syphons	First	80	25	2716	0.05	0.6	0.7	0.7	...	2.46	1.78	1795	1283	487.0
				2719	0.04	0.8	0.8	0.8	...	2.50	1.87	1864	1265	490.0
				2724	0.04	0.8	0.8	0.8	...	2.45	1.82	1708	1313	486.0
				Averages	0.04	0.7	0.8	0.8	0.8	2.47	1.82	1789	1287	487.7
	Second	120	30	2725	0.07	1.2	1.2	1.2	...	4.24	3.17	1865	1400	515.0
				2728	0.09	1.2	1.2	1.2	...	4.34	3.22	1792	1338	520.0
				2729	0.08	1.2	1.2	1.3	...	4.45	3.28	1776	1328	535.0
				Averages	0.08	1.2	1.2	1.2	1.2	4.34	3.22	1811	1355	523.3
	Third	120	45	2722	0.15	2.4	2.1	2.3	...	8.80	6.55	2114	1458	576.0
				2723	0.15	2.3	2.1	2.2	...	8.93	6.60	2071	1477	575.0
				2731	0.15	1.9	1.7	1.9	...	8.89	6.35	1747	1406	571.0
				Averages	0.15	2.2	2.0	2.1	2.1	8.87	6.50	1977	1447	574.0
	Fourth	180	45	2718	0.19	2.7	2.4	2.7	...	11.43	8.24	....	1555	580.0
				2721	0.18	2.8	2.2	2.7	...	11.55	8.50	2184	1518	602.0
				2730	0.20	2.4	2.3	2.4	...	11.79	8.23	1988	1473	595.0
				Averages	0.19	2.6	2.3	2.6	2.5	11.59	8.32	2086	1515	592.3

Superheat in Branch Pipe—Deg. F.

Rates of Evaporation	First	Second	Third	Fourth
Superheat Without Syphons	180.5	200.3	236.8	261.0
Superheat With Syphons	160.2	192.2	243.9	260.2
Degrees More Without Syphons	20.3	8.1	.....	0.8
Degrees More With Syphons	.....	.....	7.1	.....

The differences in steam temperature and in superheat are nearly the same; which would follow, as a matter of course, from the similarity of the boiler pressures in the two series of tests. At all rates of evaporation except the third, the non-syphon locomotive produced higher steam temperatures and higher superheat; whereas at the third rate both these quantities were greater with the syphons. At the first rate of evaporation the difference in superheat amounts to 20.3 degrees, in favor of the non-syphon engine. At the three higher rates the differences in superheat are so much smaller as to have little practical importance; they vary in such manner as to almost exactly offset one another; and it is fair to say that at these three higher rates of evaporation the superheat produced with and without syphons was substantially the same.

It should be pointed out that since superheat increases as the rate of evaporation is increased, and since the rates of evaporation are not precisely alike in the two series, the direct results of the tests which have been compared in the preceding paragraph are not strictly comparable; and in order to be so, would need to be adjusted as were the evaporation and efficiency values presented in Chapter V. Such adjustment, however, would amount to practically nothing at the first rate of evaporation, where the actual hourly evaporations in the two test series were almost identical; and at the three higher rates the adjustments would be so small as to entail no change whatever in the general conclusion drawn with respect to superheat.

21. *Drafts.*—The average draft values are presented in columns 18 to 24 of Table 8, and they are plotted in Fig. 11. The plotted averages in this figure are so related that the curves there drawn represent with considerable accuracy the general relations between draft and rate of evaporation for both series of tests. The variations in draft with rate of evaporation are great enough to make it misleading to compare the test averages directly, without adjusting them for differences in evaporation rate; and comparisons must therefore be based, instead, upon the curves drawn in Fig. 11.

The draft in front of the diaphragm, at the lowest rate of evaporation, is about 0.1 inch of water more with the syphons than without them; and at the highest rate, about 0.2 inch more. These differences

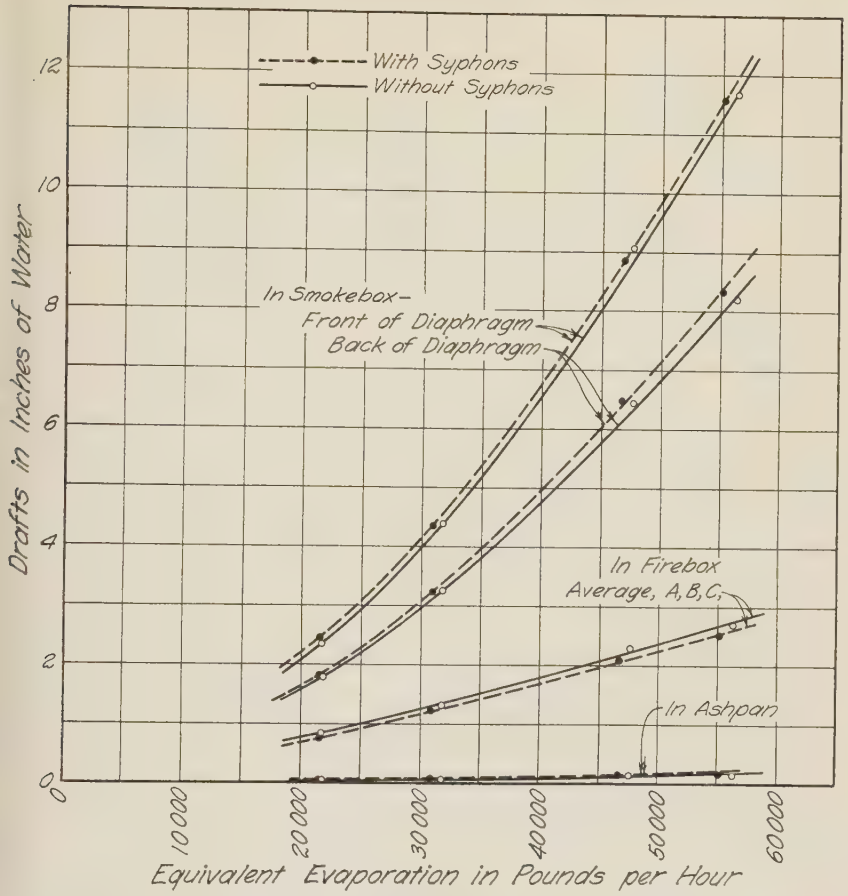


FIG. 11. DRAFT IN THE SMOKEBOX, FIREBOX, AND ASHPAN, AT VARIOUS RATES OF EVAPORATION

constitute, respectively, approximately 4 per cent and 2 per cent of the corresponding total draft values. In other words, in order to attain with the syphon-equipped engine the same rates of evaporation as with the non-syphon engine, it would have been necessary to maintain from two to four per cent more draft in front of the diaphragm—probably because of the slight additional resistance offered by the syphons to the flow of the gases. At all rates of evaporation the difference between draft in the firebox and draft in the ashpan was less with the syphons than without them—by about 0.1 inch of water. This, presumably, indicates that the firebed during the second series

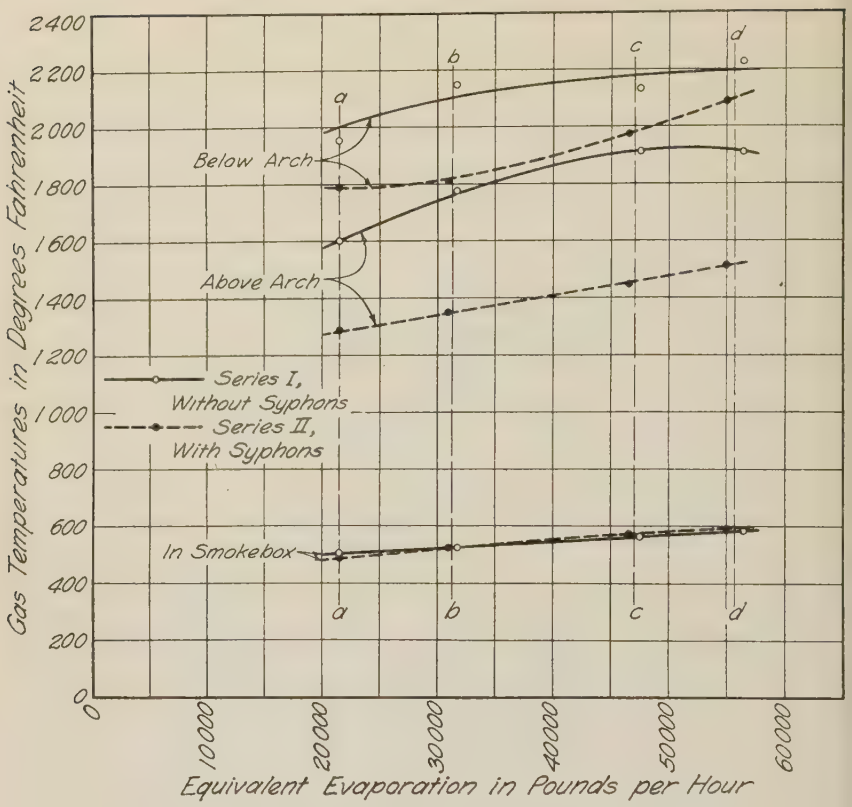


FIG. 12. GAS TEMPERATURES IN THE FIREBOX AND SMOKEBOX, AT VARIOUS RATES OF EVAPORATION

of tests was, on the average, somewhat thinner or cleaner than during the first series.

22. *Temperature of the Gases.*—The temperature of the gases was measured at three points—two in the firebox and one in the smokebox—by means of thermocouples whose location is shown in Figs. 15, 16, and 17. The couple for measuring firebox temperatures below the arch was located about a foot away from the right-hand side-sheet, almost directly under the rear edge of the arch, 26 inches above the grate about midway of its length, and 18 inches below and about 22 inches away from the lower rounded part of the right-hand syphon. The couple for firebox temperatures above the arch was placed 12 inches behind the back tube-sheet, 26 inches below the crown-sheet,

and 6 inches to the right of the boiler center line; with respect to the right-hand syphon, this couple was, consequently, 12 inches ahead of its front contour and 2 inches closer to the boiler center than the inward face of the syphon. The thermocouple for measuring smokebox temperatures was placed below the table plate and a little behind the deflector plate.

The gas temperatures are tabulated in the last three columns of Table 8; and the average temperatures for each rate of evaporation, both with and without syphons, are plotted in Fig. 12. The curves drawn in Fig. 12 represent not only the general relations between gas temperature and rate of evaporation; but, with the sole exception of the curve for firebox temperature below the arch, without syphons, they represent accurately the actual average test results —and even in this one instance the curve deviates from the test results by amounts which do not exceed 2.8 per cent. Comparison of the gas temperatures attained with and without syphons in both firebox and front-end may therefore properly be made by means of the curves of Fig. 12. Such comparison will be made at four rates of evaporation, and the rates chosen are the means of the actual average test values of equivalent evaporation, namely, 21 585, 31 344, 47 118, and 55 741 pounds per hour. These are the rates used for comparing, in Chapter V, the evaporation per pound of coal and the efficiency; they are represented in Fig. 12 by the vertical lines *a*, *b*, *c*, and *d*.

23. *Firebox Temperature Below the Arch.*—The temperatures below the arch are represented by the uppermost pair of curves in Fig. 12. They may be summarized thus:

Gas Temperatures Below the Arch—Deg. F.

Evaporation Rate—lb. per hr	21 585	31 344	47 118	55 741
Temperature Without Syphons	2 010	2 094	2 182	2 200
Temperature With Syphons	1 790	1 820	1 973	2 097
Degrees Less With Syphons	220	274	209	103

The temperature with syphons was less at all rates of evaporation, by amounts which vary, as indicated, from 103 to 274 degrees; considering all four rates, the general average difference is 202 degrees. These differences, great as they are, are less than those prevailing above the arch; but further comment on this is reserved until both temperatures are discussed.

24. *Firebox Temperature Above the Arch.*—The temperatures above the arch are represented by the lower pair of curves in the upper part of Fig. 12. They may be summarized as follows:

Gas Temperatures Above the Arch—Deg. F.

Evaporation Rate—lb. per hr	21 585	31 344	47 118	55 741
Temperature Without Syphons	1 612	1 763	1 912	1 913
Temperature With Syphons	1 286	1 353	1 460	1 520
Degrees Less With Syphons	326	410	452	393

Above the arch the temperature of the gases was less with syphons than without them at all four rates of evaporation, by amounts which vary from 326 to 452 degrees. The minimum difference occurs at the lowest rate and the maximum difference at the third rate. The general average decrease in temperature, for all four rates, is 395 degrees.

25. *Discussion of Firebox Temperatures.*—In any consideration of the firebox temperatures, the location of the pyrometer thermocouples should be borne in mind. In addition to what has already been said in Section 22, it may be pointed out that the couple below the arch was situated 26 inches above the grate; its distance from the top of the firebed varied therefore from about 20 inches to about 8 inches as the tests progressed and the fire grew in thickness. Crosswise of the firebox this couple was about 22 inches from the nearer syphon leg and 12 inches from the side-sheet; lengthwise of the firebox it was approximately over the middle of the grate. Considering the right-hand half of the firebox, this thermocouple was consequently roughly midway between the arch and the fire and a little to the right of the center of this space. The thermocouple used for measuring temperatures above the arch was placed about halfway between the front contour of the syphons and the rear tube-sheet—12 inches from each. Between the two syphons there was a space 16¼ inches wide, bisected by the central plane of the boiler; and this couple lay in the forward continuation of this space, six inches off the boiler center line.

Following the customary practice in measuring furnace temperatures, neither of these thermocouples was protected from radiant heat. The temperature measured by them is consequently a composite of the radiant heat received by the couple and the heat imparted to it by convection from the gases making contact with the pyrometer element; and there is the usual uncertainty as to how closely the measured temperature represents the true temperature of the gases. Notwithstanding this uncertainty the recorded temperatures, for the sake of brevity, are referred to as "gas temperatures" throughout Sections 22 to 25—and also in Section 26 dealing with smokebox temperatures, although here the uncertainty arising from the action of radiant heat is not so great.

The differences in firebox temperatures with and without syphons presented in Sections 23 and 24 can be accounted for only in insignificant degree by such variations in the conditions of combustion as existed between the two series of tests. These differences are undoubtedly due almost entirely to the action of the syphons; great as they are, they are easily credible when adequate consideration is given to the large amount of heating surface added by the syphons, and to the favorable position in which this additional firebox surface is placed.

The firebox heating surface (including arch tubes) without the syphons is 266.6 square feet and with them, 321.6 square feet—an increase of 55 square feet or 20.6 per cent. With a firebed of average depth, about 40 square feet of firebox heating surface in Engine 1742, immediately bounding the firebed, is relatively ineffective; and if this be excluded, the increase, with syphons, in really active heating surface amounts to about 24 per cent. This additional heating surface is ideally placed to absorb the radiant heat from the fuel bed and from the arch; and it is likely also that it receives from the incandescent gas traversing the center of the firebox radiant heat which, in the plain firebox, might not be fully absorbed by the side-sheets. As far as heat transfer by convection is concerned, the syphons are in an equally favorable position; for the gases passing them probably have a higher velocity than exists elsewhere within the firebox and the turbulence of these gases is at least as great as anywhere else within the boiler. In addition, the velocity of the mixture of water and steam over the inner surfaces of the syphons is probably greater than over any of the other heating surfaces. All these factors taken together seem sufficient to account for the great differences in firebox temperatures in the non-syphon and the syphon-equipped locomotive.

As indicated in Sections 23 and 24, the general average difference in temperature below the arch was 202 degrees, whereas above the arch it was 395 degrees. This two-fold increase in the relative absorption of heat is understandable when we recall that the pyrometer element above the arch was placed beyond the syphons and that the difference in temperatures here recorded is consequently a measure of the full effect of the syphons, whereas below the arch the temperature is recorded at a point where the syphons have not yet exerted their full effect.

26. *Smokebox Temperatures.*—The values of the temperature of the gases in the smokebox are given for each test in the last column

TABLE 9
THE RELATION BETWEEN BRANCH-PIPE AND SMOKEBOX TEMPERATURES

Equivalent Evaporation	Without Syphons			With Syphons		
Mean of Test Averages, represented in Fig. 12 by the lines a, b, c, d	Temperature of Steam in Branch Pipe	Temperature of Gases in Smokebox	Excess of Steam Temp. Over Gas Temp.	Temperature of Steam in Branch Pipe	Temperature of Gases in Smokebox	Excess of Steam Temp. Over Gas Temp.
lb. per hr.	deg.	deg.	deg.	deg.	deg.	deg.
1	2	3	4	5	6	7
Line a. 21 585	558	505	53	539	488	51
Line b. 31 344	575	527	48	573	527	46
Line c. 47 118	608	561	47	618	575	43
Line d. 55 741	631	580	51	632	594	38

of Table 8. The average values for each group of tests at like rates of evaporation, in each series, are plotted in Fig. 12; and the curves drawn in this figure represent the average test results with considerable accuracy. The smokebox temperatures derived from these curves may be summarized as follows:

GAS TEMPERATURES IN THE SMOKEBOX—DEG. F.

Evaporation Rate—lb. per hr	21 585	31 344	47 118	55 741
Temperature Without Syphons	505	527	561	580
Temperature With Syphons	488	527	575	594
Degrees More Without Syphons	17	0	...	...
Degrees More With Syphons	...	0	14	14

These smokebox temperatures, in themselves, require little comment. They are normal and such as would be expected in a superheater locomotive under conditions of good combustion; as would be anticipated, the temperatures rise gradually as the rate of evaporation (and of combustion) increases. The differences between the temperatures without and with syphons are so small as to be negligible.

One question, however, very naturally arises with respect to these temperatures; namely, why is the gas temperature in the smokebox practically the same in both series of tests, notwithstanding the fact that in Series II, with the syphons, the gas enters the tubes and flues at a temperature nearly 400 degrees lower, on the average, than during the tests of Series I? The answer to this question involves consideration of the steam temperature and the degrees of superheat existing in the branch pipe; and these values,* although they have already been

*The values of steam temperature and superheat here used are derived from the curves of Fig. 10, and apply to common mean rates of evaporation. They are so derived in order that they may be more strictly compared with the smokebox temperatures, which are similarly adjusted to common evaporation rates. Because of this fact they differ slightly from the steam temperature and superheat values presented earlier in this chapter, which are the direct test averages, not so adjusted. The maximum difference, however, between corresponding values is less than four degrees.

presented, are for convenience repeated here—the superheat values, immediately below; and the steam temperatures, in columns 2 and 5 of Table 9.

DEGREES OF SUPERHEAT IN THE BRANCH PIPE

Evaporation Rate—lb. per hr	21 585	31 344	47 118	55 741
Superheat Without Syphons	181	199	235	259
Superheat With Syphons	160	196	244	261
Difference in Superheat	+21	+3	−9	−2

Had the superheat been much less with the syphons than without them, that difference might have been made the basis of an answer to the foregoing question. There is practically no difference in superheat, however, except at the lowest rate of evaporation. No explanation of the similarity of smokebox temperatures can be built, therefore, upon the superheat data.

The differences between branch-pipe temperature and smokebox temperature do, however, provide the basis for an explanation. These differences are shown in columns 4 and 7 of Table 9. It is to be observed that both without and with syphons the temperature of the steam in the branch pipe was greater, at all rates of evaporation, than the temperatures of the gases under the table plate—by amounts which vary from 38 to 53 degrees. This excess is substantially the same without and with syphons. How much drop in gas temperature occurs from the time the gases pass the superheater header and the forward ends of the superheater units, until they reach the thermocouple which measures the gas temperature under the table plate is not known. It must be little and, what is more to the point, it must be the same with and without syphons. Since the smokebox temperatures are alike with and without syphons, it follows that the temperatures of the gases as they passed the superheater header must also have been alike. In view of the conditions here outlined it appears unreasonable to assume that, either with or without syphons, the terminal temperature of the gases could have been less than it was. It could not have been much less without causing a reversal of the flow of heat—that is, without compelling the superheated steam to give back part of its heat to the gases as they passed the header. It might, of course, be argued that because of the lower average gas temperature in the flues during the syphon series, the terminal temperature must have been actually lower and that there must have been just such a reversal of heat flow at the header, which brought the gas temperature at that point up to what it was in the non-syphon series; but such an hypothesis is nullified by the fact that as much superheat was produced with the syphons as without them.

This review of the facts seems to warrant the following inferences: Apparently the superheater surface was sufficient to abstract from the gases, during the tests with syphons, the amount of heat it was designed to abstract, in spite of the fact that the average temperature of the gases as they traversed the flues was less than during the tests without syphons. In other words, the superheater took its required amount of heat although the total heat available as the gases passed through the body of the boiler was less. It would follow, of course, that during the tests with syphons the heat transmitted to the *water* surrounding the tubes and flues must have been less than during the tests without syphons. If these views be accepted, it would seem that the gains in heat transmission made by the syphons within the fire-box must have been even greater than would be inferred by considering merely the overall gains in evaporation and efficiency discussed in Chapter V—sufficiently greater to offset the decreased transmission to the water in the body of the boiler.

27. *Variations in Rate of Firing.*—As was stated in Chapter IV, a record was kept during each test of the time required to fire each thousand-pound barrow-load of coal, in order to check the regularity of the firing. During the first series of tests, without the syphons, it was observed that for the first six or seven barrow-loads there was a progressive increase in the time required to fire each half-ton—not always a uniform increase, but one with an unmistakable general trend. After these six or seven half-tons had been fired the firing rate became more nearly uniform; that is, there was in its trend no further general increase or decrease. These facts are embodied in Table 10, which shows for each test the time to fire successive half-tons of coal. This table also shows the weight of coal fired before the beginning of each test. The average firing times for each group are shown also in Fig. 13, where, however, in order to make the figure less confusing, the time to fire successive tons, instead of half-tons, is plotted. The variation occurs at all four rates of evaporation; and although the difference in minutes diminishes at the higher rates, the differences, when expressed as a percentage of the more uniform firing rate finally attained, are roughly alike at all four rates of evaporation. This gradual increase in time to fire equal weights of coal—which implies a gradual decrease in firing rate—occasioned no surprise, nor was it regarded as altogether unusual.

Soon after beginning the tests of the second series, with the syphons, it was remarked that there was in the beginning of these tests

TABLE 10
FIRING CONDITIONS

Series	Evaporation Rate	Test Number	Coal Fired Before Start of Test	Time in Minutes to Fire Each 1000 Pounds of Coal																		
			lb.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th
Series I Without Syphons	First	2702	3950	18	23	25	18	29	22	21	25	29	23	22	25	19	29	27	20	24	19	28	35
		2703	2590	20	21	28	21	24	21	25	23	30	21	23	20	25	30	23	28	27	22	26	26
		2706	4600	17	19	19	25	14	25	17	25	18	35	27	24	20	28	27	24	23	28	24	24
		Average	3713	18	21	24	21	22	23	21	24	26	26	24	23	21	29	26	24	25	23	26	28
	Second	2701	.....	12	16	15	18	14	19	15	16	18	16	20	17	16	18	15	18	15	17	18	19
		2704	3379	14	13	16	15	17	16	15	18	16	17	16	16	18	15	19	17	14	16	19	18
		2707	2841	12	16	13	15	15	18	14	16	14	16	21	17	13	17	19	20	13	18	15	20
		Average	3110	13	15	15	16	15	18	15	17	16	16	19	17	16	17	18	18	14	17	17	19
	Third	2705	7000	10	7	8	14	9	8	13	10	10	10	10	11	10	11	12	12	9	11	11	13
		2708	5000	7	7	9	12	10	9	10	11	10	11	9	11	12	11	10	11	11	9	12	11
		2714	5640	9	8	12	10	11	10	10	10	10	14	11	8	10	11	15	9	8	11	9	14
		Average	5880	9	7	10	12	10	9	11	10	10	12	10	10	11	11	12	11	9	10	11	13
	Fourth	2710	4602	8	7	8	9	8	7	10	8	8	8	10	10	7	9	10	7	9	9	10	8
		2712	5530	7	6	8	11	4	9	10	8	10	9	9	7	9	10	8	9	9	9	9	8
		2713	4288	7	8	8	9	8	8	9	7	9	10	8	9	7	9	10	10	8	7	9	10
		Average	4807	7	7	8	10	7	8	10	8	9	9	9	9	8	9	9	9	9	8	9	9
Series II With Syphons	First	2716	2646	32	28	27	25	25	25	24	26	25	24	26	26	24	24	26	26	24	26	23	27
		2719	2686	30	30	30	26	27	24	27	23	25	27	27	28	23	27	26	27	25	25	25	26
		2724	4188	30	30	28	26	26	25	25	26	26	25	24	29	24	27	24	26	25	26	26	26
		Average	3173	31	29	28	26	26	25	25	25	25	25	26	28	24	26	25	26	25	26	25	26
	Second	2725	3664	21	20	20	17	20	17	18	19	18	17	18	17	18	19	17	17	19	18	17	19
		2728	5124	21	21	19	17	18	18	19	17	18	18	17	18	19	19	17	17	18	18	19	18
		2729	4390	21	20	21	17	18	18	18	17	17	18	17	18	15	18	17	18	18	17	17	17
		Average	4393	21	20	20	17	19	18	18	18	18	18	17	18	17	19	17	17	18	18	18	18
	Third	2722	5920	15	13	14	12	11	11	10	12	10	12	11	11	12	11	12	11	11	12	12	11
		2723	5855	14	13	13	11	13	12	11	12	11	10	10	12	12	11	12	11	10	12	10	11
		2731	5726	15	12	13	11	12	10	11	10	11	11	13	11	11	11	12	11	12	11	11	12
		Average	5834	15	13	13	11	12	11	11	11	11	11	11	11	12	11	12	11	11	12	11	11
	Fourth	2718	5738	11	9	9	10	10	9	10	8	9	10	8	9	10	9	9	10	8	9	9	9
		2721	6050	12	10	9	10	10	9	10	9	10	9	9	8	9	10	8	9	9	10	8	9
		2730	6378	10	11	11	9	9	10	10	8	10	7	10	10	10	9	9	9	9	10	9	9
		Average	6055	11	10	10	10	10	9	10	8	10	9	9	9	10	9	9	9	9	10	9	9

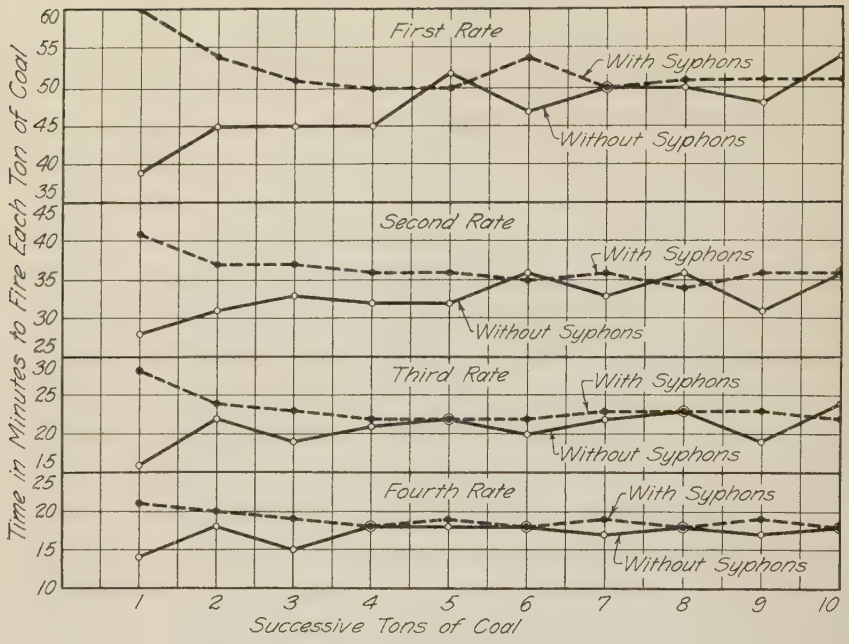


FIG. 13. TIME REQUIRED TO FIRE SUCCESSIVE TONS OF COAL, AT EACH OF THE FOUR RATES OF EVAPORATION

also a variation in rate of firing (roughly equal in percentage to that prevailing in Series I), but that it had the opposite sense; that is, the time to fire the earlier half-tons, instead of increasing, grew less and less until from four to six half-tons had been fired, after which the rate of firing became approximately uniform. The specific facts are presented in Table 10 and Fig. 13. This difference in performance of the syphon-equipped locomotive continued to show itself in each test until the conclusion of the series, and it was ultimately accepted as representing a difference inherent in the action of the syphons. In considering this difference, it should be remembered that the fireman was firing to maintain the steam pressure against an unvarying steam demand and succeeded in maintaining nearly constant pressure; that the fire was kept practically level from the beginning to the end of all tests; and that, furthermore, these remarks apply with equal force to the tests of both series.

Discussion of this difference in the performance of the syphon-equipped engine brought out the question as to whether the difference was one which manifested itself only during the initial test period,

TABLE 11
HEAT DISTRIBUTION

Series	Evaporation Rate	Test Conditions (Nominal)		Boiler Efficiency	Loss of Heat (Per Cent) Due To:							
		Speed R.P.M.	Cut-off Per Cent	Per Cent	Moisture in Coal	Moisture in Air	Hydrogen Content of Coal	Sensible Heat in Escaping Gases	Thermal Value of Escaping Combustible Gases	B. t. u. in Cinders	B. t. u. in Ash	Radiation and Unaccounted for
Series I Without Syphons	First	80	25	69.19	0.60	0.25	4.53	13.02	1.16	0.71	6.17	4.37
	Second	120	30	70.76	0.60	0.23	4.71	12.93	1.21	0.86	3.56	5.14
	Third	120	45	67.64	0.61	0.37	4.75	14.91	0.99	2.61	3.24	4.88
	Fourth	180	45	66.59	0.54	0.31	4.74	11.36	1.08	5.23	3.78	6.37
Series II With Syphons	First	80	25	77.62	0.53	0.24	4.50	10.95	0.25	0.86	3.64	1.03
	Second	120	30	76.11	0.56	0.25	4.62	11.67	0.39	1.75	4.81	—0.16
	Third	120	45	74.11	0.57	0.26	4.85	12.58	0.43	3.68	4.54	—1.02
	Fourth	180	45	69.93	0.57	0.23	4.79	12.12	0.49	5.87	4.22	1.78

with a fresh fire, or whether if the engine were stopped for a considerable time during the progress of a test and then started, this variation in firing rate would again occur. In order to try to answer this question a supplementary test—No. 2732—was planned and run after the conclusion of the other tests. Appendix C presents the graphical record for this test, an explanation of its meaning, and a summary of the facts disclosed by it. It is sufficient here to state that this test was run at the lowest rate of evaporation, that is at 80 r.p.m. and 25 per cent cut-off; and that the conditions of the test were like those of the regular tests of Series II, except that the engine was twice stopped and started after the original start. The gradual decrease in time required to fire successive half-tons of coal occurred after these stops and starts in the same way and in almost the same amount as during the initial period of this and the regular tests; and the conclusion drawn from the supplementary test is that this variation will manifest itself whenever the syphon-equipped engine is started after a stop of any considerable duration.

28. *Distribution of the Heat.*—Table 11 presents in the customary form the data concerning the distribution of the heat contained in the coal. The values there shown are the averages for each group of tests at each rate of evaporation, in both series. Similar results for the individual tests are given in the tables of Appendix D. The values of boiler efficiency, or the percentages of the heat units in the coal transmitted to the steam, are shown in the fifth column. These are

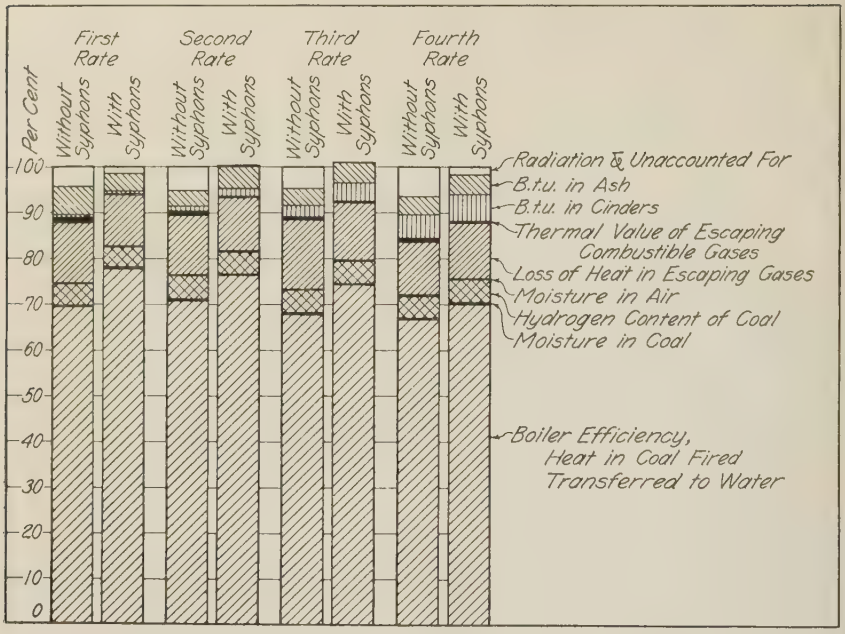


FIG. 14. HEAT DISTRIBUTION DIAGRAMS, FOR EACH OF THE FOUR RATES OF EVAPORATION

TABLE 12
CALORIFIC VALUES OF THE COAL, CINDERS, AND ASH

Series	Evaporation Rate	Test Conditions (Nominal)		Heating Values, B. t. u. per Pound				
		Speed R.P.M.	Cut-off Per Cent	Coal as Fired	Dry Coal	Cinders	Ash in Pan	Ash on Grate
Series I Without Syphons	First	80	25	12 060	12 802	7380	4838	5924
	Second	120	30	11 899	12 616	7416	3379	5061
	Third	120	45	11 887	12 605	8928	3658	4842
	Fourth	180	45	11 715	12 325	9762	3905	5734
Series II With Syphons	First	80	25	11 721	12 350	6271	2994	3834
	Second	120	30	11 961	12 634	7734	4448	4400
	Third	120	45	11 828	12 491	9287	4223	3854
	Fourth	180	45	11 946	12 610	9800	4357	3861

the efficiency values already presented and discussed in Chapter V. The succeeding columns of the table show the percentages of heat lost through the various avenues of loss designated in the column headings. Comparison of these losses may perhaps be more conveniently made

by means of the graphs presented in Fig. 14. The average heating values of the coal, the ash, and the cinders are shown in Table 12, which is here included for the light it may throw on the relations existing between the various heat losses of Table 11.

VII. Cylinder Performance and General Performance

It is the purpose, in this chapter, to present the main test results relating to the cylinder performance and to the performance of the locomotive as a whole. As in all other parts of the body of the bulletin, the results considered are those for the 24 accepted tests, during each of which 20 000 pounds of coal were fired. The results of cylinder and general performance likely to be of most interest are assembled here in Table 13; other details are given in the tables in Appendix D.

In view of the facts that the thermic syphon can directly affect only boiler performance and that its direct effects have been discussed in the preceding chapters, it seems unnecessary to present here much discussion of the results relating to general and cylinder performance, which the syphon can influence only indirectly. The arrangement in Table 13 permits their convenient comparison; but some of these results should be compared with caution, and with due consideration of the fact that they may be affected by such differences in conditions as existed in the two series of tests—differences, for example, in duration of the tests, in rate of evaporation, and in heating value of the coal. The necessity of taking into consideration such differences in conditions is well illustrated in the discussion of indicated horsepower presented beyond.

29. *Duration of the Tests.*—The duration of the tests, as indicated in column 11 of Table 13, was as follows:

Rates of Evaporation	First	Second	Third	Fourth
Duration Without Syphons—hrs	7.961	5.472	3.483	2.850
Duration With Syphons—hrs	8.700	6.061	3.872	3.128

Remembering that in all tests of both series 20 000 pounds of coal were fired, these duration records, taken at their face value, provide a rough practical indication of the superiority of the syphon-equipped engine. The duration values with syphons, however, need to be a little discounted at all rates of evaporation; because the syphon-equipped locomotive, while it took longer to burn ten tons of coal, was producing at each rate a little less steam per hour. If the duration values were discounted on this basis, they would nevertheless remain greater at all rates.

30. *Indicated Horsepower.*—The values of average indicated horsepower developed during each group of three tests with the non-syphon

TABLE 13

CYLINDER PERFORMANCE AND GENERAL PERFORMANCE

General Test Conditions					Equivalent Evaporation per Hour	Average Actual Speed			Average Actual Cut-off	Duration of Test	Equivalent Length of Run	Horsepower			Drawbar Pull	Steam Consumed		Dry Coal Consumed		Efficiency, Percentage of B.t.u. in Coal Converted to Work at the Drawbar
Without or With Syphons	Rate of Evaporation	Nominal Speed R.P.M.	Nominal Cut-off Per Cent	Test Number		Revolutions per Minute	Miles per Hour	Piston Speed Feet per Minute				Indicated	At the Drawbar	Lost in Friction		Per Indicated Horsepower Hour Pounds	Per Drawbar Horsepower Hour Pounds	Per Indicated Horsepower Hour Pounds	Per Drawbar Horsepower Hour Pounds	
Code Item Nos. ☞					Pounds	107	109	111	Per Cent	Hours	Miles	224	236	243	Pounds	232	240	230	239	246
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Series I Without Syphons	First	80	25	2702	21 809	80.04	14.34	400.20	24.7	8.033	115.16	884.7	710.5	174.2	18 578	18.78	23.46	2.65	3.31	6.00
				2703	21 277	80.04	14.34	400.20	24.8	8.083	115.88	922.7	678.9	243.8	17 752	17.61	23.98	2.53	3.44	5.76
				2706	21 737	80.03	14.33	400.15	24.8	7.767	111.29	928.3	653.2	275.1	17 091	17.95	25.65	2.59	3.70	5.41
				Averages	21 608	80.04	14.34	400.18	24.8	7.961	114.11	911.9	680.9	231.0	17 807	18.11	24.36	2.59	3.48	5.72
	Second	120	30	2701	31 334	120.45	21.57	602.25	32.0	5.567	120.03	1445.1	1187.2	257.9	20 638	16.46	20.04	2.33	2.84	7.12
				2704	32 232	120.00	21.49	600.00	32.4	5.450	117.09	1446.2	1120.9	325.3	19 957	17.00	21.93	2.39	3.09	6.49
				2707	31 604	120.00	21.49	600.00	29.5	5.400	115.99	1405.3	1089.9	315.4	19 016	17.13	22.09	2.50	3.22	6.28
				Averages	31 723	120 15	21.52	600.75	31.3	5.472	117.70	1432.2	1132.7	299.5	19 737	16.86	21.35	2.41	3.05	6.63
	Third	120	45	2705	46 924	120.05	21.50	600.25	45.9	3.500	75.18	1940.3	1630.6	309.7	28 438	18.17	21.65	2.77	3.30	6.17
				2708	47 857	119.59	21.42	597.95	46.5	3.417	73.12	....	1607.0	290.2	28 131	18.92	22.34	....	3.41	5.78
				2714	47 935	120.01	21.49	600.05	47.4	3.533	75.90	1960.7	1720.4	240.3	30 018	18.19	20.74	2.74	3.13	6.56
				Averages	47 572	119.88	21.47	599.42	46.6	3 483	74.73	1950.5	1652.7	280.1	28 862	18 43	21.58	2.76	3.28	6.17
	Fourth	180	45	2710	57 253	179.94	32.23	899.70	47.8	2.850	92.21	2244.8	1829 9	414.9	21 288	18.92	23.21	2.96	3.63	5.63
				2712	55 912	180.04	32.25	900.20	48.0	2.850	91.83	2241.6	1825.0	416.6	21 218	18.50	22.72	2.98	3.66	5.62
				2713	56 107	180.19	32.27	900.95	48.3	2.850	91.90	2276.0	1879.8	396.2	21 842	18.34	22.21	2.94	3.56	5.87
				Averages	56 424	180 06	32.25	900.28	48.0	2.850	91.98	2254.1	1844.9	409.2	21 449	18.59	22.71	2.96	3.62	5.71
Series II With Syphons	First	80	25	2716	21 577	80.00	14.33	400.00	24.8	8.567	122.70	891.7	677.0	214.7	17 713	18.77	24.72	2.48	3.26	6.33
				2719	21 573	80.01	14.33	400.05	24.4	8.800	126.24	901.7	676.3	225.4	17 696	18.52	24.70	2.40	3.20	6.42
				2724	21 532	80.00	14.33	400 00	23.8	8.733	125.22	883.4	673.4	210.0	17 619	18.93	24.84	2.46	3.23	6.38
				Averages	21 561	80.00	14.33	400.02	24.3	8 700	124.72	892.3	675.6	216.7	17 676	18.74	24.75	2.45	3.23	6.38
	Second	120	30	2725	31 027	120.03	21.50	600.15	30 0	6.100	131.21	1377.9	1101.4	276.5	19 208	17.22	21.55	2.27	2.83	7.09
				2728	30 860	119.98	21.49	599.90	30.0	6.117	131.34	1354.3	1044.8	309.5	18 229	17.42	22.58	2.27	2.95	6.79
				2729	31 006	120.01	21.49	600.05	30.3	5.967	128.23	1374.7	1141.7	233.0	19 921	17.26	20.78	2.31	2.78	7.28
				Averages	30 964	120.01	21.49	600.03	30 1	6.061	130.26	1369.0	1096.0	273.0	19 119	17.30	21.64	2.28	2.85	7.05
	Third	120	45	2722	46 947	120.00	21.49	600.00	47.5	3.917	84.17	1937.1	1644.2	292.9	28 688	18.10	21.33	2.49	2.94	6.93
				2723	46 870	119.99	21.49	599.95	46.1	3.850	82.70	1948.4	.....	.....	.....	18 01	....	2.52	....	....
				2731	46 175	120.26	21.54	601.30	47.6	3.850	83.00	1925.5	1739.1	186.4	30 273	17.95	19.87	2.56	2.83	7.25
				Averages	46 664	120.08	21.51	600.42	47.1	3.872	83 29	1937.0	1691.7	239.7	29 481	18.02	20.60	2.52	2.89	7.09
	Fourth	180	45	2718	54 796	180.03	32.24	900.15	46.4	3.100	99.87	2189.4	1739.4	450.0	20 229	18.59	23.40	2.80	3.52	5.83
				2721	55 634	179.88	32.22	899.40	46.5	3.133	100.72	2217.0	1833.2	383.8	21 333	18.66	22.57	2.73	3.30	6.09
				2730	54 743	179.98	32.23	899.90	45.7	3.150	101.80	2180.5	1733.9	446.6	20 172	18.66	23.47	2.75	3.47	5.75
				Averages	55 058	179.96	32.23	899.82	46.2	3.128	100.80	2195.6	1768.8	426.8	20 578	18.64	23.15	2.76	3.43	5.89

TABLE 14
INDICATED HORSEPOWER AND WORK DONE IN THE CYLINDERS

Rate of Evaporation	Without Syphons			With Syphons		
	Indicated Horsepower Developed	Duration of the Tests Hours	Total Work Performed During the Tests Millions of Foot-pounds	Indicated Horsepower Developed	Duration of the Tests Hours	Total Work Performed During the Tests Millions of Foot-pounds
1	2	3	4	5	6	7
First	911.9	7.961	14 374	892.3	8.700	15 371
Second	1432.2	5.472	15 517	1369.0	6.061	16 429
Third	1950.5	3.483	13 451	1937.0	3.872	14 850
Fourth	2254.1	2.850	12 720	2195.6	3.128	13 598

engine at like rates of evaporation are shown in column 2 of Table 14; and during tests with the syphon-equipped engine in column 5. It is to be noted that the values there shown are less with syphons at all four rates of evaporation. In view of the fact that the pressures, the speeds, and the cut-offs are almost exactly alike in both series of tests, these horsepower values, superficially considered, may seem either inherently incorrect or inconsistent with the conclusions reached in Chapter V as to the gains effected by the syphons. They are, however, neither the one nor the other, and the apparent inconsistency disappears if we take into consideration two differences in the conditions prevailing in the two series of tests, namely, the differences in duration and in the weight of steam generated per hour. The duration values are repeated in columns 3 and 6 of Table 14; they are considerably greater, at all four rates, for the tests with syphons. The steam generated per hour, on the other hand, was somewhat less with the syphons at all four rates—the deficiencies being, respectively, 0.22, 2.39, 1.91, and 2.42 per cent at the first, second, third, and fourth rates. As has been indicated in Chapter VI, had the draft in the syphon-equipped engine been greater by from 4 to 2 per cent it would have generated, at all rates, substantially the same weight of steam per hour as the non-syphon engine; but there would have remained differences in test duration similar to those exhibited in Table 14—not as great, but certainly not much less. With evaporation thus equalized we should have, at each rate, the same horsepower as with the non-syphon locomotive, but maintained for a longer period. Such adjusted values of power and duration would enable us to make a just comparison of the work performed in the cylinder in both series of tests.

It is not possible, however, to find the adjustments in duration entailed by equalizing the evaporation and power values, without basing such adjustments on the gains in evaporation with syphons discussed in Chapter V. But, since the purpose of the present discussion is to prove that the relation between indicated horsepower values is not inconsistent with the gains in evaporation, it would be illogical to resort to a correction process based on these gains themselves. We must therefore accept without adjustment the direct test averages for horsepower and duration, and try to see how far the excess in duration of the tests with syphons offsets their deficiency in horsepower.

This purpose may be attained by using the direct horsepower and duration results to calculate the total work performed in the cylinders. Considering the first evaporation rate, the average total work performed in the cylinders, without syphons, was $911.9 \times 33\ 000 \times 7.961 \times 60 = 14\ 374\ 087\ 000$ foot-pounds;* whereas for the tests with syphons the work performed in the cylinders was $892.3 \times 33\ 000 \times 8.700 \times 60 = 15\ 370\ 740\ 000$ foot-pounds. These values of cylinder work are given in columns 4 and 7 of Table 14, together with the values at the three other rates of evaporation, similarly derived. Comparison of these values shows that the total work performed—for an expenditure of 20 000 pounds of coal—was greater at all rates of evaporation with the syphon-equipped locomotive. This showing, which is based directly upon the indicated horsepower values, is in entire agreement with the conclusions with respect to the superiority of the syphon-equipped locomotive based upon the record of evaporation per pound of coal or of boiler efficiency. The increases in cylinder work performed with the syphons, when expressed as percentages of the work done without them, are of the same general order of magnitude as the gains in evaporation; although there is no precise equivalence. Precise agreement, however, is not to be expected, in view of the various slight differences existing between the two series of tests—differences in such quantities as steam pressure, steam temperature, superheat, and cut-off.

31. *Steam Consumption.*—The steam consumed per indicated horsepower per hour varies with both speed and cut-off; and usually the record of steam consumption for a locomotive is presented as a series of curves showing its variation with respect to both these factors. In these tests, however, only three speeds and three cut-offs were used, and their various combinations do not yield enough points

*Since one horsepower equals 33 000 foot-pounds per minute; and the test duration, in minutes, equals duration in hours x 60.

TABLE 15
STEAM CONSUMED PER INDICATED HORSEPOWER HOUR

Rates of Evaporation	First	Second	Third	Fourth
Steam Used, Without Syphons—lb	18.11	16.86	18.43	18.59
Steam Used, With Syphons—lb	18.74	17.30	18.02	18.64
Speed, Without Syphons—r.p.m	80.0	120.2	119.9	180.1
Speed, With Syphons—r.p.m	80.0	120.0	120.1	180.0
Cut-off, Without Syphons—per cent	24.8	31.3	46.6	48.0
Cut-off, With Syphons—per cent	24.3	30.1	47.1	46.2

to define curves of steam consumption. All that can be done, therefore, to summarize the record, is to assemble, as in Table 15, the average values of steam consumed per indicated horsepower hour, of speed and of cut-off from Table 13—from columns 17, 7, and 10, respectively.

32. *Efficiency.*—Column 21 of Table 13 gives the average values of general or "overall" efficiency attained during the tests; that is, the percentage of the number of heat units contained in the coal which, during the tests, was converted into useful work at the engine drawbar. These values are as follows:

EFFICIENCY OF THE LOCOMOTIVE—PER CENT

Rates of Evaporation	First	Second	Third	Fourth
Efficiency Without Syphons	5.72	6.63	6.17	5.71
Efficiency With Syphons	6.38	7.05	7.09	5.89

APPENDIX A

The Locomotive

As has been stated in Chapter II, the locomotive used for the tests was Illinois Central Railroad locomotive No. 1742, of the 2-8-2 type, built in 1915 by the Lima Locomotive Works, and bearing the builder's serial number 5046. Its general design is shown in Fig. 1 in that chapter, and in Figs. 15, 16, and 17 in this appendix. The boiler, the superheater, the front-end, and the auxiliary equipment have all been adequately described in Chapter II. The boiler construction and dimensions are shown in Figs. 18 and 19. The syphons also have been described in Chapter II and are shown in Figs. 2, 3, and 4.

Other details of the locomotive design are given in the following list which embodies all the information demanded by the American Society of Mechanical Engineers' Test Code for Locomotives; and the numbers affixed to the various items of the list are the numbers used in that code.

(9)	Rated tractive force (m.e.p. = 0.85 b.p.), lb	58 588
(10)	Driving wheels, number of pairs	4
(11)	Driving wheels, nominal diameter, in	63
(12)	Driving wheels, average circum., measured, ft	15.761
(13)	Driving wheels, average diam., measured, in	60.203
(14)	Engine truck wheels, number of pairs	1
(15)	Engine truck wheels, diameter, in	30
(16)	Trailing wheels, number of pairs	1
(17)	Trailing wheels, diameter, in	45
(18)	Wheelbase, driving, ft	16.5
(19)	Wheelbase, total, ft	35.166
(20)	Gauge of wheels, in	56.5
(21)	Total weight of locomotive, with water at second gauge cock and average fire, lb	282 700
(22)	Weight on leading truck, lb	26 300
(23)	Weight on drivers, lb	218 300
(24)	Weight on trailing truck, lb	38 100
(25)	Weight of tender, loaded, lb	167 500
(26)	Capacity of tender, coal, tons	15
(27)	Capacity of tender, water, gal	9000
(28)	Boiler, type	Straight top, radial stay
(29)	First ring, outside diameter, in	82
(30)	Tubes, number	262
(31)	Tubes, outside diameter, in	2
(32)	Tubes, thickness	0.134 in., No. 10 gauge
(33)	Superheater flues, number	36
(34)	Superheater flues, outside diameter, in	5⅜
(35)	Superheater flues, thickness	0.148 in., No. 9 gauge
(36)	Length between tube sheets, ft.-in	20–4⅞
(37)	Fire area of tubes and flues (combined internal cross-section), sq. ft.	7.585
(38)	Arch tubes, number	4
(39)	Arch tubes, outside diameter, in	3
(40)	Arch tubes, thickness	0.180 in., No. 7 gauge

(41)	Arch tubes, length, in	120.5
(42)	Firebox, length (at grate), in	120⅝
(43)	Firebox, width, in	84
(44)	Firebox, depth (perpendicular above grate), at the front, in	78½
	at the back, in	66
(45)	Firebox, volume—without syphons, cu. ft	346.0
	with syphons, cu. ft	336.0
(46)	Fire doors, number	1
(47)	Firedoor openings, area, sq. ft	1.69
(48)	Fire doors, hand or power operation	power
(49)	Water space in boiler below second gauge cock, cu. ft	776.41
(50)	Steam space in boiler above second gauge cock, cu. ft	167.81
(51)	Grate, area, sq. ft	70.364
(52)	Grate, width, in	84
(53)	Grate, length, in	120⅝
(54)	Grate, style of	Rocking finger
(55)	Air inlets to firebox, total area, sq. ft	27.58
(56)	Air inlets through grate, sq. ft	25.89
(57)	Air inlets above fuel bed (fire door only), sq. ft	1.69
(58)	Ratio of air inlets through grate to grate area, per cent	36.8
(59)	Ratio of total air inlets to grate area, per cent	39.2
(60)	Area of air inlets to ashpan, sq. ft	11.0
(61)	Ratio of ashpan air inlets to area of tube and flue openings, per cent	145.1
(62)	Superheater, type	A
(63)	Superheater elements, number	36
(64)	Superheater elements, average length in flue, ft.-in	17–8
(65)	Superheater tubes, outside diameter, in	1½
(66)	Superheater tubes, thickness, in	0.150
(67)	Brick arch	"Security"
(68)	Feedwater heater	None
(69)	Stoker	None
(70)	Reverse gear	(pneumatic), Ragonnet
(71)	Air compressor	Two N.Y.A.B. Co. cross-compound
(72)	Electric generator	Buda-Ross
(73)	Grate shaker	Hand lever
(74)	Injectors	Simplex: right side, No. 11; left side, No. 10
(75)	Safety valves	Two 3½-inch, muffled and one 3½-inch, open
(76)	Thermic syphons:	
	During tests 2700 to 2714, inclusive	None
	During tests 2715 to 2732, inclusive	Two
(77)	Circulating plates	None
(78)	Booster engines	None

Heating surface—based upon the inside of firebox; and the fireside of tubes, flues, superheater, arch tubes, and syphons, sq. ft.:

		Without Syphons	With Syphons
(79)	Total	4742.2	4797.2
(80)	Of the tubes and flues	3401.2	3401.2
(81)	Of the firebox, including syphons	235.0	305.8
(82)	Of the superheater	1074.4	1074.4
(83)	Of the arch tubes	31.6	15.8
(83a)	Total water-evaporating surface	3667.8	3722.8
(84)	Exhaust nozzle, type	Round, with ⅜-inch knife-edge bridge	
(85)	Exhaust nozzle dimensions	6¼-in. diameter, with ⅜-inch bridge	
(86)	Exhaust nozzle area, net, sq. in	28.34	

		Right Side	Left Side
(87)	Cylinder diameter, in	27.078	27.078
(88)	Piston stroke, in	30.00	30.00
(89)	Piston-rod diameter, in	4.000	4.531
(90)	Tail-rod diameter	None	None

(91)	Clearance, head end, per cent	8.70	8.70
(92)	Clearance, crank end, per cent	8.87	8.90
(93)	Valves, type		Piston
(94)	Steam ports, area, sq. in		52.01
(95)	Valve travel, maximum, in		6.0
(96)	Steam lap, in		1.25
(97)	Exhaust clearance, in		0.125
(98)	Valve motion, type		Walschaerts
		Without Syphons	With Syphons
(99)	Ratio of total heating surface to grate area	67.40	68.18
(100)	Ratio of fire area through tubes and flues to grate area	0.108	0.108
(101)	Ratio of firebox heating surface to grate area	3.79	4.57
(102)	Ratio of tube and flue surface to firebox heating surface	12.76	10.58
(103)	Ratio of firebox volume to grate area	4.92	4.78

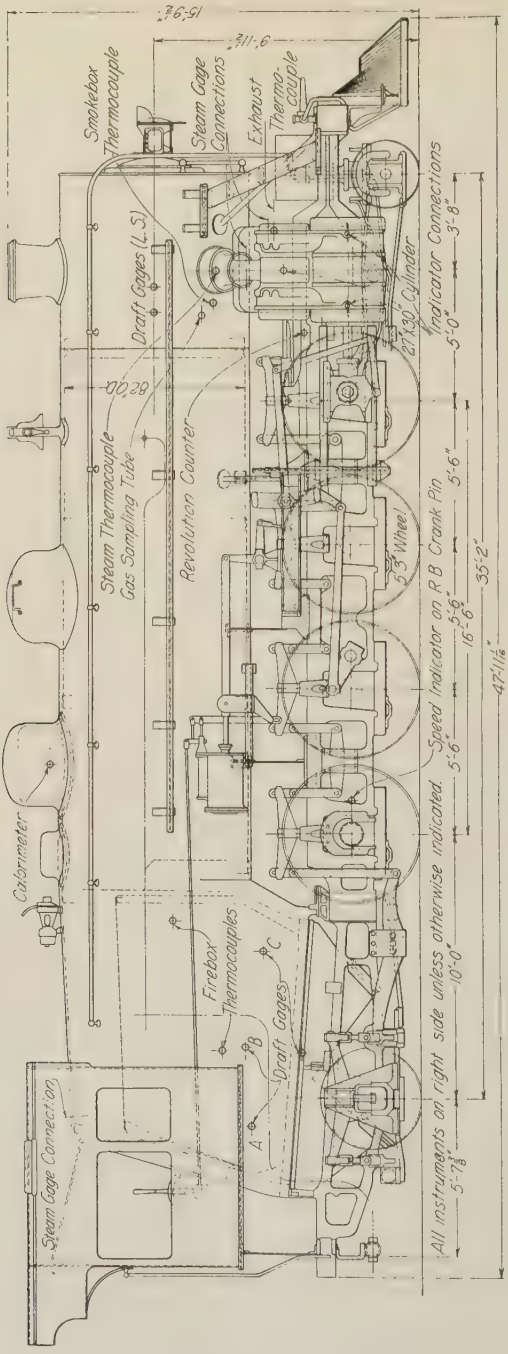


FIG. 15. ENGINE NO. 1742—SIDE ELEVATION

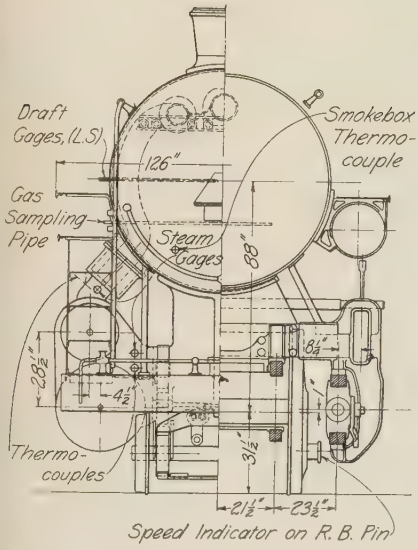


FIG. 16. ENGINE NO. 1742—FRONT ELEVATION AND SECTION

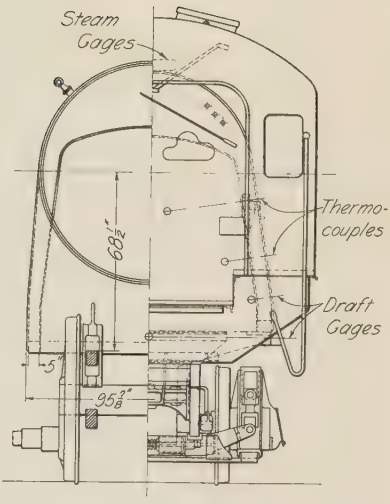


FIG. 17. ENGINE NO. 1742—REAR ELEVATION AND SECTION

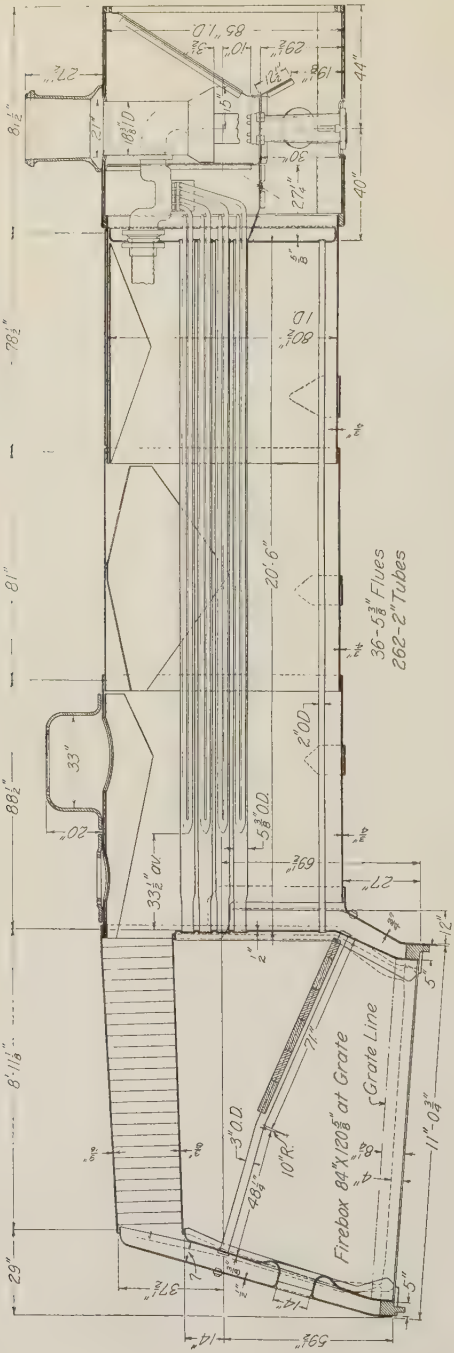


FIG. 18. THE BOILER OF ENGINE NO. 1742—LONGITUDINAL SECTION

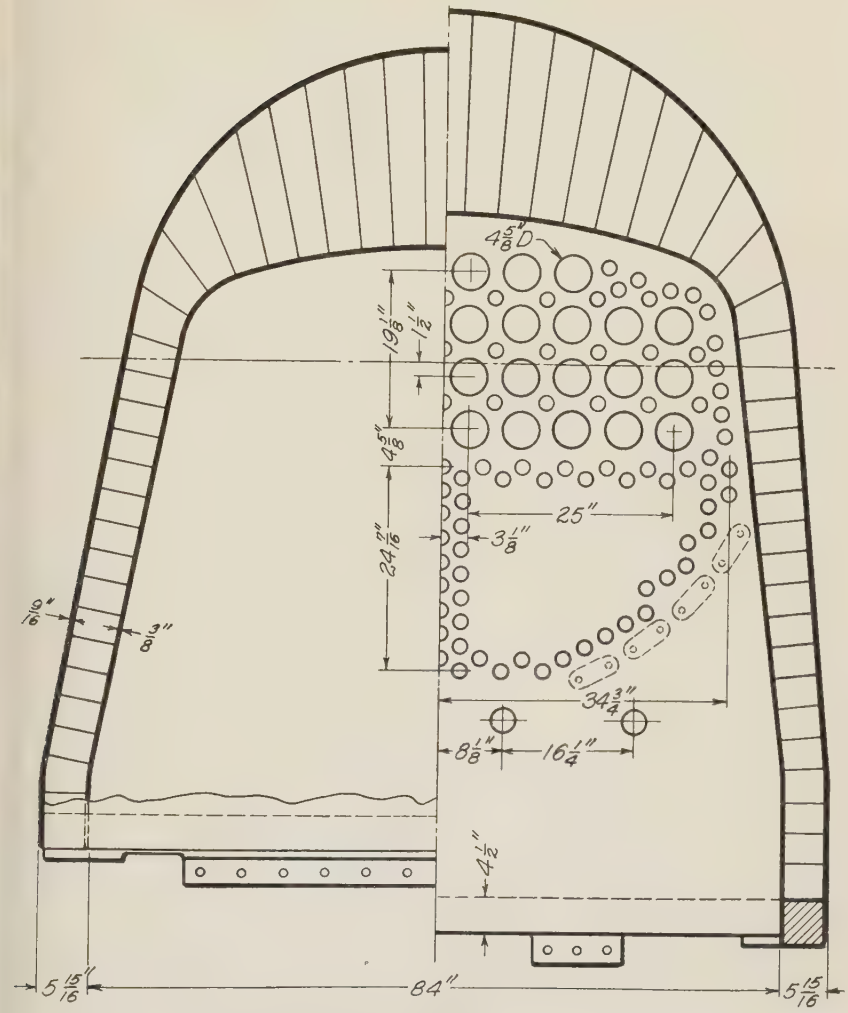


FIG. 19. THE BOILER OF ENGINE NO. 1742—CROSS-SECTIONS AT THE FIREBOX

APPENDIX B

Test Procedure and Methods

The purpose of this section is to supplement Chapter IV, in which the general test conditions, the firing methods, methods of starting and stopping tests, the delivery of the feedwater, the weighing of the fuel and water, and the control of cut-off and speed are fully presented. It deals with further details of test procedure and equipment.

1. *The Laboratory.*—The laboratory has been described fully in several publications: Bulletin 82 of the University of Illinois Engineering Experiment Station; Proceedings of the American Railway Master Mechanics' Association, Volume 46, 1913; Proceedings of the Western Railway Club for March, 1913. An interior view of the plant, with a locomotive mounted and ready for testing, is shown in Fig. 6 in Chapter IV. Since its establishment, additional supporting wheels, bearings and absorption brakes have been added to the laboratory equipment, and many minor improvements have been made in the details, but no changes have been made which affect the principles of operation of the major equipment. It seems necessary therefore to present here only a brief description of the cinder separator. The exhaust steam, hot gases and entrained solid matter, received from the locomotive stack in an overhead duct, are discharged, by means of a blower, tangentially into a brick-lined separator chamber 18 feet in diameter and 36 feet high, surmounted by a 45-foot chimney. An extension of the chimney, 8½ feet in diameter, reaches downward into the separator, the bottom of this extension reaching below the bottom of the breeching through which the gas mixture is received. The lower portion of the separator chamber is an inverted cone. Solid matter, as a result of the downward and whirling motions imparted to the smoke stream, drops to the bottom of the cone, where a trap permits its removal. The gaseous portion flows downward and around the lower edges of the chimney extension and is thence discharged. This separator has been found fully effective, there being no discharge of solid matter from the top of the chimney.

2. *Cleaning and Inspection.*—The boiler of the locomotive was washed out before the tests began, and it was given a thorough cleaning after the syphons were installed. It was washed out twice during the first series of tests, and it was blown down, drained, and refilled

six times in addition. During the second series it was blown down, drained, and refilled ten times. The tubes and flues were cleaned and the front-end was opened and cleaned after every test. The machinery of the locomotive was under almost continuous inspection, and the lubrication of all parts was carefully watched. After preliminary runs (which are not included among the tests discussed in this bulletin) minor adjustments were made in the valve gear to equalize the cut-off; and at various stages of the regular tests minor work was done on the piston-rod packing, grease cellars, rod-stub wedges, and similar parts. Between the two series of tests the locomotive received the regular monthly government inspection and was found in good condition.

3. *Calibrations and Observation Interval.*—All instruments used in the tests were calibrated before the beginning of the first series, again between the first and second series, and at the close of the second series. Many instruments received intermediate calibrations as well. During the tests, readings of all non-recording instruments were taken at ten-minute intervals. Indicator cards were taken at the same time; but in the long tests, if it was found that the cards were uniform (as they invariably were) the number of sets of four cards worked up was reduced to eighteen or twenty.

4. *Sampling and Analysis of the Coal, Ash, and Cinders.*—In view of the fact that the coal all came from the same portion of the same mine, and because of the similarity of the methods by which all portions of the consignment were handled, the method of sampling for chemical analysis specified in the A.S.M.E. Code was somewhat simplified. The process actually used was as follows: During the filling of each barrow of coal to be used in the tests, three shovelfuls from different portions of the pile, which would normally have gone into the barrow, were placed in sample cans. During the firing of twenty barrows of coal a sample weighing about one thousand pounds was thus obtained. This thousand-pound sample was emptied on a clean metal plate and crushed with tamps to about a two-inch maximum dimension; it was then mixed, coned, and quartered three times, reducing the sample to about 120 pounds. This reduced sample was then further crushed on the plate by tamping to quarter-inch lumps, and twice mixed, coned and quartered, leaving thirty pounds. The thirty-pound remainder was crushed to coarse dust in a ball mill, and emptied on a clean piece of canvas; here it was finally mixed by rolling in the canvas and quartered down to a two-pound analysis sample.

The ash from the test is divided into two parts: that accumulating in the ashpan, and that remaining on the grate at the close of the test. After the conclusion of a test the "pan ash" was removed first, and the pan and the floor beneath were left clean. The grate was then shaken with the ashpan hopper doors open, and the grate ash was quenched. Each lot of ash was weighed and sampled, the sampling process being as follows: From each barrow of ash from three to five shovelfuls were removed and placed in a sample can, in this way obtaining samples of a gross weight of 200 to 250 pounds, representing all portions of the contents of the ashpan or grate. In a few cases the total ash in the pan was so little that the entire amount was used as a sample. The gross samples (two for each test—grate ash and pan ash) were dumped on clean concrete pavement, and any large lumps were broken down to about a two-inch maximum dimension. The sample was then mixed by shovelling, and coned and quartered down to about a twenty-five pound sample. This remainder was spread on the pavement, crushed to pea-size, mixed, and quartered down to a quart-jar analysis sample, weighing about one and one-half pounds.

The sampling of cinders consisted merely of taking several small scoops from each wheel-barrow load that came from the separator, making a quart-jar sample. The cinders were perfectly homogeneous as far as could be seen, but by the method used a representation of all periods of the test was secured.

The chemical analyses of the coal, ash, and cinder samples were made by the University Applied Testing Bureau, under the direction of Mr. J. M. Lindgren, Technical Analyst. The methods of analysis used were those prescribed by the American Society for Testing Materials.

5. *Determination of Total Ash per Test.*—Aiming at equality in the amount of combustible on the grate at both ends of a test, the A.S.M.E. Code implies that in so far as may be practicable the fire depth should be the same at the end as at the beginning. In these tests, although this goal was kept in view, it proved impracticable to maintain the same fire depth; attempts to do so entailed so much shaking of the grates as to throw considerable amounts of unburned coal into the ashpan and to seriously impair the condition of the fire. The firebed consequently had to be allowed to grow in thickness during all tests. The material remaining on the grate at the end of the test (which has been referred to in preceding paragraphs as "grate ash") comprised, therefore, not only live fire, but the accumu-

lation of ash which, had it been feasible to do so, would have been shaken into the ashpan during the progress of the test; and this ash contained presumably the same percentage of carbon as the ash actually shaken into the pan. In view of these facts the total weight of ash produced during each test has been taken as the sum of the weights of "pan ash" and "grate ash" found at the end of the test, diminished by the weight of the live fire remaining on the grate at the end. In order to determine this weight of live fire, it has been assumed that the weight of live fire at the end was equal to the weight of fire at the beginning, and its weight has been calculated from the observed depth and the estimated density of the fire at the beginning. To find the heating value remaining in the total ash per test thus derived, its weight has been multiplied by the heating value per pound found by analysis of the pan ash.

6. *Sampling and Analysis of the Flue Gas.*—Flue gas samples were taken every hour, the period during which the sample was drawn lasting from twenty to twenty-five minutes. The samples were collected over mercury and stored thus if necessary; but in general the samples were analyzed as soon as taken. For the determination of the percentages of the principal constituents of the flue gas a standard Orsat apparatus was used, the burette being graduated to 0.2 cc. The Orsat results should be correct to about one tenth of one per cent. The University Applied Testing Bureau analyzed, for each test, a sample which had passed through the Orsat apparatus, and uniformly reported that no quantity of hydrogen or methane that could be measured remained. This analysis (by the slow-combustion method) also demonstrated that all carbon monoxide had been removed in the Orsat analysis.

7. *Screen Analysis of the Coal.*—A screen analysis was made corresponding to each carload of coal used in the tests; and an additional analysis was made to correspond with a part of a carload which had been transferred to another car, and considerably broken up in the process of transfer. For the screen analysis three box screens were used: these consisted of metal boxes fitting together, each box having, in its bottom, round holes of the diameter used to specify the size of the screen. The coal was thus divided into four size-components, and the work was done with sufficient care so that the total of the four components checked the total weight of the sample within one pound. The sample for screen analysis was a thousand-pound barrow of coal

loaded in the expectation that it was to be fired as test coal. This barrow of coal was in every case inspected by the representatives of the coöperating companies and the University, and agreed upon as, in their judgment, fairly representative of the carload.

8. *Temperature Measurements.*—Gas temperatures were taken in the firebox below and above the arch, and in the front-end below the table-plate. In the firebox platinum — platinum-rhodium thermocouples were used, and the front-end couple was of iron-constantan. Firebox temperatures were read on a Leeds & Northrup two-point recording pyrometer, except for the above-the-arch temperatures in the second series, where the readings were mostly below the range of the pyrometer; such readings were taken on a portable potentiometer. The front-end temperatures were read on a Leeds & Northrup single-point recording pyrometer. The firebox thermocouples were calibrated by comparison with standard pyrometers in the University heat-treatment laboratory, the calibrations being made with the lead wires attached. The front-end pyrometer was calibrated in a hot oil-bath against a standard thermometer. Steam temperatures were measured in the steam pipe and exhaust passage on the right side of the engine by iron-constantan thermocouples, calibrated in the same manner as the front-end thermocouple; and these temperatures were recorded on the chart of a Leeds & Northrup two-point recording pyrometer.

9. *Measurements of Steam Pressure and Quality.*—Steam pressures were read on the back head of the boiler, in the steam pipe leading to the right cylinder, in the exhaust passage from this cylinder, and in the right steam chest. On the back head and on an adjacent gauge board were located three steam gauges: the regular locomotive gauge (an eight-inch gauge with five-pound graduations), a standard test-gauge ten inches in diameter and graduated to one pound, and an eight-inch recording gauge. The pressure in the steam pipe was read from a six-inch gauge which had five-pound graduation and a throttling connection to reduce the variation in pressure resulting from the cylinder action. The exhaust pressure was indicated by a similar five-inch gauge, also throttled, in the third rate and high rate tests; but in the tests at the two lower rates exhaust pressures were read from a mercury manometer. Every pressure gauge received at least four calibrations and adjustments during the course of the tests. The steam pressure in the valve chamber was recorded at intervals on the

right-side head-end indicator cards. To determine the quality of the steam a throttling calorimeter was employed. This instrument had an opening of 0.04 inch diameter, and discharged about 12 pounds of steam per hour. This amount, being an insignificant proportion of the total, was ignored in the steam calculations involving it.

10. *Draft Measurements.*—Drafts were measured in the front-end, both in front of and behind the diaphragm, at three points in the firebox, and in the ashpan directly below the grate. For the front-end readings Ellison vertical gauges with extended scales were used, ordinary U-tube check gauges being connected in parallel. For the A and C readings in the firebox (see Fig. 15) ordinary water manometers were used; for the B reading and for the ashpan reading Ellison differential gauges were used.

11. *Speed Measurements.*—The approximate speed of the locomotive in revolutions per minute was indicated by an electric tachometer—a small generator connected directly to the right back crank pin indicating the voltage developed on a meter graduated to read directly in revolutions per minute. This device was chiefly for the guidance of the operator who controlled the speed by varying the brake load. For accurate indications of speed a revolution counter, actuated by the reducing motion on the right side of the locomotive, was read exactly on each observation signal; and speed adjustment was made to correspond with the number of revolutions made since the last reading, the operator responsible for speed adjustment being informed after each reading as to the excess or deficiency during the preceding interval.

12. *Indicated Horsepower Measurements.*—Four indicators were used throughout the tests. On the right side in all tests a pair of Crosby outside-spring indicators were used. On the left side through part of the tests a pair of identical indicators were used; and during the remainder a pair of integrating Maihak indicators were employed. Calibrated 100-pound springs were used throughout. The reducing motion, which gave a card three inches long, was of the double-slotted lever type, operated by an arm extending downward from the crosshead.

APPENDIX C

Supplementary Test No. 2732

In Chapter VI it was pointed out that during the tests with the syphon-equipped locomotive there was, at the beginning of each test, a gradual decrease in the time required to fire successive half-tons of coal; that is, there was during the firing of the first four or five thousand-pound barrowloads, while the fire thickness was probably building up faster than it did later in the run, a gradual increase in the rate of firing. The purpose of supplementary test No. 2732, which is discussed in this appendix, was to determine whether this increase in firing rate manifests itself only at the beginning of a run, or whether, if the locomotive were stopped and started later in the test, it would again show itself.

Test No. 2732 was accordingly so planned that the engine would be twice stopped and started after the original start, the interval between stops being long enough for the firing rate to go through this period of increase and then settle down to a practically uniform rate as it did during the regular tests. The general procedure for the test is outlined in paragraphs (A) to (F), which follow.

(A) The preparations for the test were in every respect like those for the regular tests at the lowest rate of evaporation; the starting procedure was also the same.

(B) After five barrowloads (5000 lb.) of coal had been fired, the test was stopped in the usual way; that is, when, after the last shovelful of this coal had been fired, the boiler pressure began to fall, this portion of the run was declared ended, and the engine was stopped.

(C) Upon stopping the engine, the injector was shut off and the fire door opened. Conditions remained thus for about thirty minutes during which, in each of the two stops, the grates were once shaken.

(D) The locomotive was then started again, and the fireman began building up the fire in preparation for the second running period of the test. The preparatory operations were the same as those for the original start; that is, the engine was run long enough to attain the desired operating conditions (of load, speed, etc.), and then kept running under these conditions for an additional fifteen-minute or twenty-minute period before the second running portion of the test was started.

(E) After the second running portion of the test was started, five barrowloads of coal were again fired, as in the first portion; the engine

TABLE 16
THE VARIOUS PERIODS OF SUPPLEMENTARY TEST NO. 2732

Period of the Test	Duration of Period		Coal Fired during Period
	Limits	Minutes	Pounds
Firing Up	6:00— 8:20	140	1850
Preliminary Running Before Original Start	8:20— 9:00	40	1660
FIRST RUNNING PERIOD	9:00—11:20	140	5000
First Stop	11:20—11:51	31	285
Preliminary Running Before Second Start	11:51—12:20	29	1450
SECOND RUNNING PERIOD	12:20— 2:38	138	5000
Second Stop	2:38— 3:04	26	507
Preliminary Running Before Third Start	3:04— 3:35	31	1774
THIRD RUNNING PERIOD	3:35— 5:38	123	4000

was then stopped and handled as explained in paragraphs (B) and (C), and finally started once more, as in (D).

(F) After firing, in the last running period of the test, four barrowloads of coal, it was seen that the test had served its purpose and it was finally discontinued—the final stop being made as explained in (B).

The left injector was continuously in operation during the running periods, and shut off during the stops. During stops the right injector was used as required, to make up the losses through the safety valves and the blower. The shaking of the grates was left to the judgment of the fireman. In general, the fire was handled during the stops about as it would ordinarily be handled during a half-hour stop on the road. Throughout the tests the usual records of weights and times were kept —for each tank of water and each barrowload or partial load of coal. In addition, the time of each firing and the number of scoopfuls of coal fired were observed and recorded on a chronograph. The duration of the various periods of this test and the amount of coal fired in each period are shown in Table 16.

A complete graphical record for this test is presented in Fig. 20. In this figure the fine vertical lines denote each 10 minutes from 8:20 A.M., when the engine was started, until 5:40 P.M., after the final stop. Beginning at the top of the figure the ten records are, in succession, as follows:

(1) A record of depth of fire, which extends throughout each running period. The scale for this record extends from 0 to 20 in.

(2) A record of boiler pressure, which continues unbroken through the entire test period.

(3) A record of drawbar pull. The pull, of course, ceased during the stops, and is not here recorded during the preliminary running.

(4) A record of the time at which the greates were shaken, and of the approximate duration of the shaking process. These facts are indicated by the short wavy lines which appear in the space allotted to the firebox temperature record.

(5) A record of temperature of the gases in the firebox, below the arch. This record continues throughout all periods of the test. Its scale extends from 1000 to 2000 deg.; during the stops, however, the temperature dropped below 1000 deg., as indicated.

(6) A horizontal line showing the operation of the injectors. This record has no scale at the left of the diagram, since it is used to show simply the times at which the two injectors were started and stopped. Both were never in operation at the same time.

(7) A record of the time required to fire one thousand pounds of coal. This, in one sense, is the chief record of the test, since the test was undertaken in order to discover what variations in firing rate occurred. The record consists of a series of short horizontal lines whose height above the base line shows the number of minutes required to fire the corresponding half-ton. Firing of the third half-ton in the first running period, for example, began at 10:02 A.M. and finished at 10:28, requiring therefore 26 minutes; and the horizontal line corresponding to this half-ton is consequently drawn at a distance above the base line which represents 26 minutes (see the scale at the extreme left). The corresponding firing rate, expressed in pounds fired per hour, is 2307; and this amount may be read on the second (inner) scale. Within the stops and the preliminary running periods, where coal was not fired with regularity in thousand-pound lots, this record, being a mere "rate" line, is to be interpreted as showing the minutes which would have been required to fire 1000 pounds, had the coal actually used amounted to just that much.

(8) A record of the number of scoopfuls of coal fired and of the time at which they were fired. This record consists of dots. The height at which each dot is plotted represents, on the scale provided, the number of scoopfuls; whereas its position sidewise represents the time. Between 10:40 and 10:50, for example, three dots are plotted. They indicate that at 10:43 and also at 10:47 six scoopfuls of coal were fired; and that again at 10:50 coal was fired—this time, five scoopfuls.

(9) A record of the weights of coal fired. This consists of figures denoting weights of coal, and of very short vertical lines which extend

Depth of Fire in Inches
20
16
12
8
4
0
Start of 1st Run
Fire Depth
Boiler Pressure in lb. per sq. in.
190
180
170
Boiler Pressure
Drawbar Pull in Pounds
20000
18000
16000
Drawbar Pull
Firebox Temperature in Degrees Fahrenheit
2000
1800
1600
1400
1200
1000
Firebox Temperat
Left Injector
Minutes to Fire 1000 Pounds of Coal
35
30
25
20
15
10
Firing Rate in lb. per hr.
2000
2500
3000
3500
4000
Scoops of Coal at each Firing Period
8
6
4
2
0
Pre-test Coal
Coal in Pounds
250
510
1000
1000
1000
1000
Water in Pounds
2004
2001
2009
2020
2026
2028
2009
2033
2003
2007
2006
2000
2003
2000
2005
2009
2010
2020
8:20
8:40
9:00
9:20
9:40
10:00
10:20
10:40
11:0

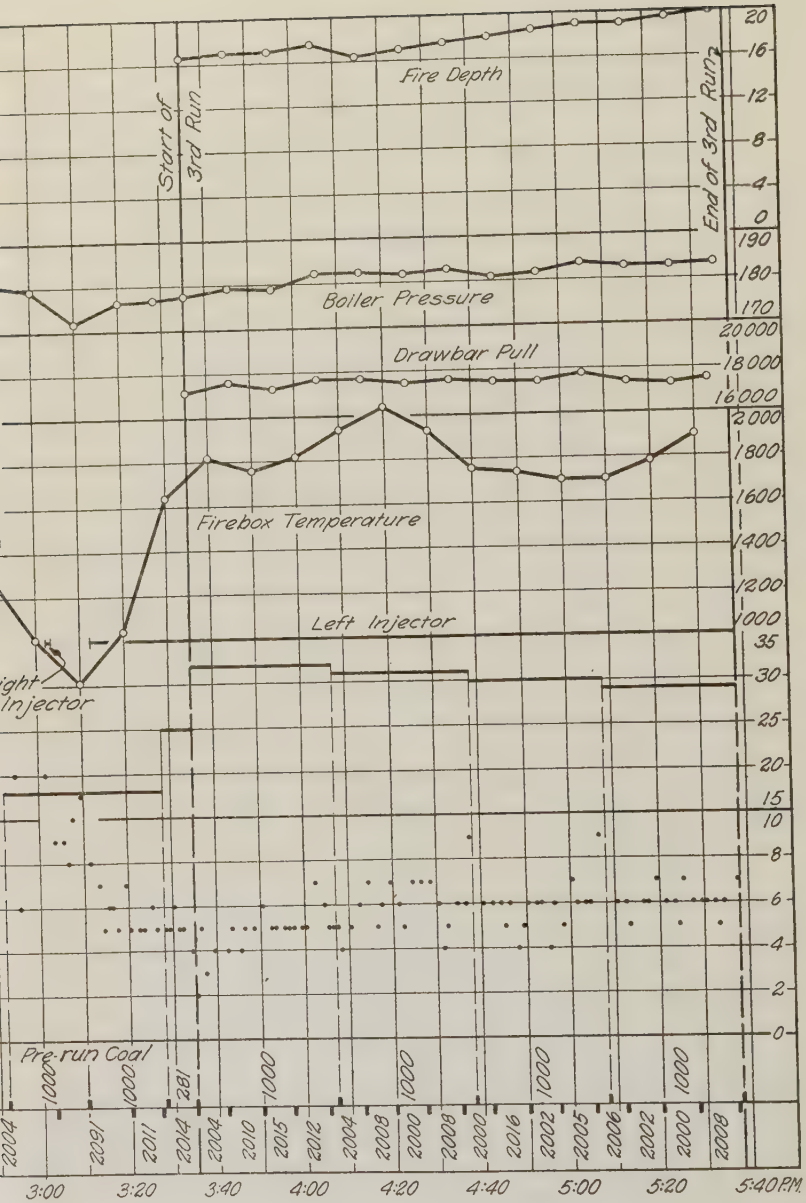

Start of 3rd Run
End of 3rd Run
Fire Depth
Boiler Pressure
Drawbar Pull
Firebox Temperature
Left Injector
ight Injector
Pre-run Coal
20
16
12
8
4
0
190
180
170
20000
18000
16000
2000
1800
1600
1400
1200
1000
35
30
25
20
15
10
8
6
4
2
0
1000
1000
281
1000
1000
1000
2004
2009
2011
2014
2004
2010
2015
2012
2004
2008
2000
2008
2000
2016
2002
2005
2006
2002
2000
2008
3:00
3:20
3:40
4:00
4:20
4:40
5:00
5:20
5:40 P.M.

TABLE 17
SUMMARY OF THE RESULTS OF SUPPLEMENTARY TEST NO. 2732

Minutes to Fire Successive Half-tons of Coal

	Running Periods of Test 2732		
	First	Second	Third
First Half-ton	31	31	32
Second Half-ton	31	28	31
Third Half-ton	26	29	30
Fourth Half-ton	28	25	29
Fifth Half-ton	23	24	..
Average Time	27.8	27.4	..

upward from a base line. The vertical lines define the time at the beginning and at the end of the period during which the corresponding weight of coal was fired. Immediately preceding the initial start, for example, 510 pounds of coal were fired, beginning at 8:46 and ending at 9:00 o'clock. This record provides the data from which record No. 7 is derived.

(10) A record of the feedwater injected. This consists of figures denoting weights of water contained in the weighing tank, and of short vertical lines extending downward from a base line. These verticals define the time at the beginning and at the end of the period during which the weighing tank was being emptied into the feed tank from which the injector drew its supply. Since the water level in the feed tank was kept nearly constant, the period referred to corresponds closely with the period of injection of the specified weight of water.

Inspection of Fig. 20 shows that throughout each of the running periods there was an unmistakable decrease in the time required to fire successive half-tons of coal—even in the third period, after the locomotive had been fired up for more than seven hours. The variation is, however, probably more easily seen in Table 17, which summarizes the results of this test. It is apparent that the change in firing rate occurs not only in the first running period, but in each of the two succeeding periods; and that the variation is as pronounced in the third period as in either of the others. The variations, furthermore, are closely like those which occurred during the initial periods of the low-rate tests of Series II.

APPENDIX D

Tabulated Data and Results

It is the purpose to present in this appendix the detailed results of each of the 31 regular tests run during the entire investigation. The results are given in Tables 18 to 34, inclusive, which follow. In these tables the results are first presented for the tests of Series I, run without the syphons; and then, in the lower half of each table, for those of Series II, with syphons. In each series the tests are grouped with respect to their rates of evaporation.

As has been previously stated, the results given in the body of the bulletin relate exclusively to 24 accepted tests—three tests at each of the four rates of evaporation in each of the two series—whose test numbers are listed on page 22. The tables in this appendix, however, include not only these 24 tests, but 7 other tests which, for reasons stated on page 22, were rejected from among those upon which the discussion and the conclusions given in the body of the bulletin are based. These 7 rejected tests are distinguished in Tables 18 to 34 by asterisks in the test-number columns.

In Tables 18 to 34, in addition to the values for each test, average values are given for each group of tests run at like rates of evaporation—for all quantities for which averages may logically be made. It should be particularly noted that these averages for each group are based upon all the tests shown in that group, "rejected" tests as well as "accepted" tests. As a consequence, the group averages given in Tables 18-34 are the same as the corresponding group averages used in the body of the bulletin, only for the first, second, and third rates of evaporation in the series of tests without syphons, and for the first rate in the series with syphons. All other group averages given in these tables—because these groups comprise rejected tests—differ from the corresponding group averages used in the text, the tables, and the figures in the body of the bulletin.

In arranging the data and results in the tables of this appendix the order of the item numbers of the A.S.M.E. Test Code for Steam Locomotives has been generally adhered to. Such deviations from this order as have seemed desirable are specified beyond. With a few exceptions, which are likewise specified, the methods recommended in that code for calculating derived quantities have been used in deriving the results of these tests. The steam tables used in the calcu

lations are those prepared by J. H. Keenan and published in 1930 by the American Society of Mechanical Engineers.

The following items, although they are not called for by the Code, are presented in these tables:

Boiler pressure at the beginning and end of the tests, following Code Item 121. These data are of interest in themselves and are required for the calculation of Items 188 and 189.

B.t.u. content of the ash on the grate at the close of the test, following Item 137. This information is presented as an indication of fire condition at the end of the tests; and, for the same reason, the analysis for the grate ash is given in two columns following Code Item 174.

Air used per pound of carbon burned (following Item 153) is an intermediate value of some interest.

Four items concerning the weight of ash remaining on the grate at the close of the test and the total weight of ash to be considered as produced during the test follow Code Item 165. The method of correcting for the ash which would have been in the ashpan had it been possible to shake the fire down to its starting level is explained in Appendix B.

Volatile matter in cinders, following Item 174, is useful in explaining a higher heating value of the cinders than their carbon content accounts for.

Total moist steam evaporated, following Item 189.

Total steam to the superheater, following Item 190.

B.t.u. transferred to the boiler per pound of coal fired, and the same per pound of dry coal fired, following Item 217.

Tractive effort based on mean effective pressure, following Item 234.

Values of equivalent evaporation per hour, per square foot of combined heating surface, per pound of coal as fired, and per pound of dry coal are presented in columns following Item 199. The A.S.M.E. Code presents corresponding values in terms of "Heat Transfer in Thousands of B.t.u.," but the long-continued use of equivalent evaporation as a means of comparison seems to warrant its presentation, in addition to that of the newer unit.

A list of the code items follows, with statements as to their position in this bulletin, their arrangement in the tables following, and the reasons for the omission of those not presented.

Items 1-103 deal with the dimensions and specifications of the locomotive, and are presented in Appendix A.

Items 113-114-115, 126, 183-184-185-186-187, 193, 205-205a, 235 and 242 do not apply to a locomotive without a feedwater heater, and are consequently omitted.

Items 169 and 170 are omitted because the front-end cinders, being insignificant in amount, were mixed with the stack cinders before weighing. The total weight appears as Item 171.

Item 184 is omitted because the injector overflow was returned to the feed tank.

Item 215 is omitted. It would be the same as Item 200, since there was no loss of superheated steam.

Items 106, 147, and 148 are omitted, because they define unvarying quantities or facts which are stated in the text.

Item 191 is omitted because no superheated steam was used in auxiliaries.

For the sake of convenience, Items 200 and 201 were calculated by means of the following formulas, instead of by the methods suggested in the Code:

$$\text{Item } 200 = \frac{\text{Item } 182 \pm \text{Item } 188 - \text{Item } 190}{\text{Item } 104}$$

$$\text{Item } 201 = \frac{\text{Item } 182 \pm \text{Item } 189}{\text{Item } 104}$$

The following Items are presented in the tables but somewhat out of numerical order:

Items 112, 116-117 follow Item 120
Items 118-119-120 follow Item 111
Item 201 follows Item 189
Items 216-217 follow Item 204

All of the other code items, as follows, appear in the tables nearly in numerical order and are calculated as specified in the Code: 104-105, 107-111, 121-146, 149-168, 171-174, 176-182, 188-190, 192, 194-199, 202-204, 206-214, 218-234, 236-241, 243-246.

Table 18
General Conditions

General Test Conditions		Test Number	Duration of Test	Nominal Cut-off	Speed					Temperature, Degrees Fahrenheit		
					Revolutions		Equivalent			In Laboratory		
With or Without Syphons	Rate of Evaporation		Hours	Per Cent	Per Minute	Total	Speed in Miles per Hour	Length of Run Miles	Piston Speed, Average Feet per Minute	Dry Bulb	Wet Bulb	Outdoor
Code Item ☞			104	105	107	108	109	110	111	118	119	120
Without Syphons	First	2702	8.033	25	80.04	38 579	14.34	115.16	400.20	65.50	59.75	55.67
		2703	8.083	25	80.04	38 821	14.34	115.88	400.20	54.14	46.42	45.61
		2706	7.767	25	80.03	37 284	14.33	111.29	400.15	71.93	67.43	66.79
		Average	....	..	80.04	.....	14.34	.....	400.18	....	....	....
	Second	2701	5.567	30	120.45	40 213	21.57	120.03	602.25	61.25	55.32	48.21
		2704	5.450	30	120.00	39 227	21.49	117.09	600.00	59.10	49.20	47.80
		2707	5.400	30	120.00	38 859	21.49	115.99	600.00	84.40	74.20	78.96
		Average	....	..	120.15	.....	21.52	.....	600.75	....	....	....
	Third	2705	3.500	45	120.05	25 185	21.50	75.18	600.25	62.10	54.10	52.40
		2708	3.417	45	119.59	24 496	21.42	73.12	597.95	82.17	72.79	78.47
		2714	3.533	45	120.01	25 427	21.49	75.90	600.05	86.37	77.15	81.00
		Average	....	..	119.88	.....	21.47	.....	599.42	....	....	....
		*2709	3.000	45	160.38	28 887	28.72	86.23	801.90	75.80	63.83	68.79
	Fourth	2710	2.850	45	179.94	30 891	32.23	92.21	899.70	78.70	72.30	70.60
		*2711	2.200	45	180.63	23 839	32.35	71.16	903.15	86.27	74.40	81.40
		2712	2.850	45	180.04	30 763	32.25	91.83	900.20	80.90	70.10	73.77
		2713	2.850	45	180.19	30 788	32.27	91.90	900.95	86.40	71.80	82.20
		Average	....	..	180.20	.....	32.28	.....	900.10	....	....	....
With Syphons	First	2716	8.567	25	80.00	41 106	14.33	122.70	400.00	86.80	70.50	83.10
		2719	8.800	25	80.01	42 294	14.33	126.24	400.05	80.60	65.90	77.00
		2724	8.733	25	80.00	41 949	14.33	125.22	400.00	87.60	70.30	85.00
		Average	....	..	80.00	.....	14.33	.....	400.02	....	....	....
	Second	*2715	3.000	30	120.01	20 238	21.49	60.41	600.05	64.90	61.20	58.20
		*2717	5.817	30	120.00	41 903	21.49	125.08	600.00	69.50	64.50	61.30
		*2720	5.700	30	120.04	41 039	21.50	122.50	600.20	83.70	68.70	80.00
		2725	6.100	30	120.03	43 956	21.50	131.21	600.15	88.20	71.40	85.30
		2728	6.117	30	119.98	44 001	21.49	131.34	599.90	78.04	66.74	73.44
		2729	5.967	30	120.01	42 958	21.49	128.23	600.05	79.74	64.89	75.06
		Average	....	..	120.01	.....	21.49	.....	600.06	....	....	....
	Third	2722	3.917	45	120.00	28 197	21.49	84.17	600.00	68.50	60.00	62.60
		2723	3.850	45	119.99	27 706	21.49	82.70	599.95	63.60	57.20	55.30
		*2727	3.583	45	120.08	25 849	21.51	77.16	600.40	88.30	75.00	84.80
		2731	3.850	45	120.26	27 807	21.54	83.00	601.30	83.22	72.24	73.75
		Average	....	..	120.08	.....	21.51	.....	600.41	....	....	....
	Fourth	2718	3.100	45	180.03	33 458	32.24	99.87	900.15	70.10	58.20	62.80
		2721	3.133	45	179.88	33 741	32.22	100.72	899.40	64.10	59.20	53.80
		*2726	2.800	45	180.05	30 410	32.25	90.77	900.25	88.80	73.70	85.40
		2730	3.150	45	179.98	34 105	32.23	101.80	899.90	75.76	66.65	69.27
		Average	....	..	179.99	.....	32.24	.....	899.93	....	....	....

*For the meaning of these asterisks see page 80.

Table 19
Temperatures, Humidity, and Pressures

General Test Conditions		Test Number	Temperatures, Degrees Fahrenheit						Humidity, Moisture per Pound of Air	Boiler Pressure, Gauge Pounds per Square Inch		
			Feed Water	Steam in Branch Pipe	Steam in Exhaust Passage	Gases in Smokebox	Gases in Firebox					
With or Without Syphons	Rate of Evaporation						Above Arch	Below Arch	lb.	Start of Test	Close of Test	Average
Code Item ☞			112	116	117	122	(123)	(123)	121			124
Without Syphons	First	2702	69.1	564.5	244.6	516.5	1545	1960	0.00986	174.0	181.0	180.4
		2703	67.9	561.6	247.8	504.0	1580	2017	0.00486	178 0	182.5	179.8
		2706	69.9	548.6	241.3	494.0	1678	1892	0.01300	177.0	179.0	179.8
		Average	69.0	558.2	244.6	504.8	1601	1956	0.00924	....	....	180.0
	Second	2701	68.0	583.5	255.4	542.3	1760	2140	0.00786	180.0	179.0	179.6
		2704	67.7	572.4	250.0	522.4	1757	2228	0.00500	179.0	181.0	180.1
		2707	67.7	571.8	253.5	516.0	1817	2074	0.01570	180.0	178.0	176.3
		Average	67.8	575.9	253.0	526.9	1778	2147	0.00952	....	....	178.7
	Third	2705	67.9	607.0	303.0	555.0	1934	2167	0.00730	184.0	176.0	177.9
		2708	67.0	603.0	301.0	564.0	1893	2182	0.01540	174.0	181.0	176.4
		2714	66.9	620.0	312.7	562.0	....	2060	0.01800	176.0	180.0	176.5
		Average	67.3	610.0	305.6	560.3	1914	2136	0.01357	....	....	176.9
		*2709	67.1	625.0	333.0	565.0	1920	2195	0.01000	181.0	175.0	177.8
	Fourth	2710	66.7	637.0	354.0	584.0	1920	2226	0.01510	179.0	181.5	179.0
		*2711	67.6	632.0	350.0	584.0	1873	2204	0.01540	176.5	175.0	177.6
		2712	65.9	630.0	351.0	583.0	1903	2235	0.01330	177.5	179.5	176.4
		2713	66.0	629.0	343.0	575.0	1905	2212	0.01370	176.0	180.0	176.5
		Average	66.6	632.0	349.5	581.5	1900	2219	0.01438	....	....	177.4
With Syphons	First	2716	71.4	540.0	246.0	487.0	1283	1795	0.01243	184.0	182.0	182.0
		2719	70.5	542.0	239.0	490.0	1265	1864	0.01029	184.0	184.5	184.1
		2724	71.0	535.0	237.0	486.0	1313	1708	0.01186	183.5	184.0	182.8
		Average	71.0	539.0	240.7	487.7	1287	1789	0.01153	....	....	183.0
	Second	*2715	68.3	574.0	255.0	519.0	1460	1879	0.01086	184.0	180.5	180.8
		*2717	68.2	574.5	252.5	525.0	1403	1880	0.01186	183.5	182.0	179.6
		*2720	70.0	575.3	250.1	519.0	1405	1980	0.01157	180.0	186.0	183.2
		2725	68.8	570.0	250.0	515.0	1400	1865	0.01264	182.0	184.0	182.0
		2728	67.4	572.0	250.0	520.0	1338	1792	0.01143	179.0	183.0	181.7
		2729	67.2	566.0	249.0	535.0	1328	1776	0.00971	183.0	184.0	182.6
		Average	68.3	572.0	251.1	522.2	1389	1862	0.01135	....	....	181.7
	Third	2722	66.9	621.0	311.0	576.0	1458	2114	0.00914	182.5	182.0	182.3
		2723	66.1	615.0	310.0	575.0	1477	2071	0.00857	188.0	179.0	183.2
		*2727	68.1	615.0	310.0	568.0	1390	2066	0.01550	183.0	186.0	181.8
		2731	66.1	618.0	308.0	571.0	1406	1747	0.01443	181.5	180.5	180.3
		Average	66.8	617.3	309.8	572.5	1433	2000	0.01191	....	....	181.9
	Fourth	2718	64.0	626.0	345.0	580.0	1555	....	0.00757	183.5	179.0	179.1
		2721	66.1	638.0	349.7	602.0	1518	2184	0.00971	184.5	180.0	181.8
		*2726	66.6	624.0	341.0	575.0	1552	2114	0.01429	183.0	184.0	180.1
		2730	64.1	630.0	344.0	595.0	1473	1988	0.01193	184.0	183.0	180.1
		Average	65.2	629.5	344.9	588.0	1525	2095	0.01088	....	....	180.3

*For the meaning of these asterisks see page 80.

Table 20
Pressures and Drafts

General Test Conditions		Test Number	Pressure, Pounds per Square Inch			Draft, Inches of Water					
						In Smokebox		In Firebox			In Ash Pan
With or Without Syphons	Rate of Evaporation		Steam in Branch Pipe, Gauge	Steam in Exhaust Passage, Gauge	Barometer	Front of Diaphragm	Back of Diaphragm	Point A	Point B	Point C	
Code Item ☞			125	127	128	129	130	(131)	(131)	(131)	132
Without Syphons	First	2702	176.0	1.12	14.44	2.34	1.79	0.8	0.8	0.9	0.04
		2703	176.1	1.50	14.52	2.29	1.74	0.8	0.7	0.8	0.04
		2706	178.6	1.63	14.48	2.47	1.86	0.8	0.9	0.9	0.03
		Average	176.9	1.42	14.48	2.37	1.80	0.8	0.8	0.9	0.04
	Second	2701	170.8	4.50	14.44	4.28	3.23	1.2	1.3	1.3	0.06
		2704	171.9	4.12	14.49	4.55	3.39	1.4	1.2	1.4	0.07
		2707	171.3	3.41	14.49	4.35	3.19	1.3	1.3	1.4	0.06
		Average	171.3	4.01	14.47	4.39	3.27	1.3	1.3	1.4	0.06
	Third	2705	166.9	.....	14.50	9.20	6.50	2.1	2.2	2.3	0.13
		2708	166.6	10.19	14.46	8.88	6.25	2.3	2.2	2.3	0.14
		2714	164.9	10.21	14.48	9.15	6.57	2.2	2.5	2.5	0.15
		Average	166.1	10.20	14.48	9.08	6.44	2.2	2.3	2.4	0.14
		*2709	164.4	13.61	14.44	11.14	7.71	2.1	...	2.5	0.16
	Fourth	2710	161.7	15.44	14.44	12.03	8.34	2.8	2.8	2.8	0.18
		*2711	161.7	15.40	14.40	11.80	8.39	2.8	2.9	3.1	0.17
		2712	160.9	15.27	14.27	11.48	8.16	2.3	2.1	3.1	0.17
		2713	161.1	15.19	14.42	11.60	8.12	2.7	2.8	3.0	0.17
		Average	161.4	15.33	14.38	11.73	8.25	2.7	2.7	3.0	0.17
With Syphons	First	2716	176.4	2.09	14.43	2.46	1.78	0.6	0.7	0.7	0.05
		2719	179.7	2.59	14.56	2.50	1.87	0.8	0.8	0.8	0.04
		2724	179.2	1.67	14.54	2.45	1.82	0.8	0.8	0.8	0.04
		Average	178.4	2.12	14.51	2.47	1.82	0.7	0.8	0.8	0.04
	Second	*2715	171.2	3.71	14.44	4.37	3.19	1.2	1.1	1.2	0.08
		*2717	170.8	3.74	14.43	4.25	3.07	1.2	1.2	1.1	0.10
		*2720	176.3	3.95	14.47	4.14	3.06	1.1	1.0	1.1	0.08
		2725	175.4	3.57	14.57	4.24	3.17	1.2	1.2	1.2	0.07
		2728	174.7	3.55	14.51	4.34	3.22	1.2	1.2	1.2	0.09
		2729	173.6	3.63	14.50	4.45	3.28	1.2	1.2	1.3	0.08
		Average	173.7	3.68	14.59	4.30	3.17	1.2	1.2	1.2	0.08
	Third	2722	168.5	9.69	14.47	8.80	6.55	2.4	2.1	2.3	0.15
		2723	168.8	9.80	14.54	8.93	6.60	2.3	2.1	2.2	0.15
		*2727	168.2	9.30	14.46	8.92	6.52	2.0	1.9	2.0	0.15
		2731	165.5	8.02	14.46	8.89	6.35	1.9	1.7	1.9	0.15
		Average	167.8	9.20	14.48	8.89	6.51	2.2	2.0	2.1	0.15
	Fourth	2718	160.4	14.71	14.63	11.43	8.24	2.7	2.4	2.7	0.19
		2721	162.9	14.71	14.50	11.55	8.50	2.8	2.2	2.7	0.18
		*2726	161.8	14.68	14.54	11.23	8.30	2.5	2.2	2.4	0.19
		2730	160.5	13.30	14.51	11.79	8.23	2.4	2.3	2.4	0.20
		Average	161.4	14.35	14.55	11.50	8.32	2.6	2.3	2.6	0.19

*For the meaning of these asterisks see page 80.

Table 21
Heating Values

General Test Conditions		Test Number	Heating Values, B.t.u. per Pound					
With or Without Syphons	Rate of Evaporation		Coal as Fired	Dry Coal	Combustible	Cinders	Ash in Pan	Ash on Grate
Code Item ☞			133	134	135	136	137	
Without Syphons	First	2702	12 116	12 829	14 460	7434	6196	6752
		2703	12 133	12 860	14 442	7314	6237	6431
		2706	11 930	12 716	14 528	7392	2081	4588
		Average	12 060	12 802	14 477	7380	4838	5924
	Second	2701	11 795	12 577	14 448	6304	3125	3260
		2704	11 991	12 716	14 482	7341	3217	6528
		2707	11 910	12 555	14 480	8604	3794	5396
		Average	11 899	12 616	14 470	7416	3379	5061
	Third	2705	11 782	12 509	14 444	8696	3090	4030
		2708	12 095	12 910	14 557	8738	3263	5867
		2714	11 783	12 395	14 096	9351	4622	4630
		Average	11 887	12 605	14 366	8928	3658	4842
		*2709	12 109	12 827	14 524	8550	3740	3501
	Fourth	2710	11 768	12 419	14 325	9225	4794	5204
		*2711	11 910	12 590	14 400	10033	4427	5407
		2712	11 754	12 354	14 268	10311	3443	5275
		2713	11 623	12 201	14 041	9751	3479	6723
		Average	11 764	12 391	14 259	9830	4036	5652
With Syphons	First	2716	11 653	12 317	14 183	6496	2694	4035
		2719	11 785	12 393	14 351	5805	2903	3717
		2724	11 726	12 341	14 363	6513	3384	3751
		verage	11 721	12 350	14 299	6271	2994	3834
	Second	*2715	11 794	12 507	14 279	6808	3200	3404
		*2717	11 817	12 485	14 331	7317	4807	4378
		*2720	12 086	12 709	14 412	8330	3761	4105
		2725	12 037	12 651	14 354	8112	4077	4038
		2728	11 961	12 700	14 411	7322	5818	3934
		2729	11 886	12 550	14 327	7769	3449	5228
		Average	11 930	12 600	14 352	7610	4185	4181
	Third	2722	11 797	12 465	14 313	9810	3859	3747
		2723	11 948	12 627	14 392	9028	4416	4645
		*2727	11 980	12 664	14 383	9577	4964	4045
		2731	11 738	12 382	14 282	9024	4393	3169
		Average	11 866	12 535	14 343	9360	4408	3902
	Fourth	2718	11 754	12 390	14 336	9287	4477	4612
		2721	11 999	12 669	14 358	9782	4054	3442
		*2726	11 851	12 434	14 403	9794	5574	4179
		2730	12 084	12 771	14 403	10330	4539	3529
		Average	11 922	12 566	14 375	9798	4661	3941

*For the meaning of these asterisks see page 80.

TABLE 22
COAL ANALYSIS

General Test Conditions		Test Number	Proximate Analysis, Coal as Fired					Ultimate Analysis, Coal as Fired			
With or Without Syphons	Rate of Evaporation		Fixed Carbon	Volatile Matter	Moisture	Ash	Sulphur, Separately Determined	Carbon	Hydrogen	Nitrogen	Oxygen
			Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Code Item ☞			138	139	140	141	142	143	144	145	146
Without Syphons	First	2702	48.45	35.34	5.56	10.65	3.42	67.44	4.41	1.16	7.36
		2703	46.71	37.30	5.65	10.34	3.39	65.60	5.11	1.17	8.74
		2706	47.16	34.96	6.18	11.70	3.18	64.33	4.99	1.21	8.42
		Average	47.44	35.86	5.80	10.90	3.33	65.79	4.84	1.18	8.17
	Second	2701	47.86	33.78	6.22	12.14	2.95	65.20	4.51	1.17	7.81
		2704	46.25	36.55	5.70	11.50	3.26	63.96	5.27	1.13	9.18
		2707	46.15	36.10	5.14	12.61	3.28	64.10	5.04	1.15	8.68
		Average	46.75	35.48	5.69	12.08	3.16	64.42	4.94	1.15	8.56
	Third	2705	47.35	34.22	5.81	12.62	3.23	63.55	4.91	1.23	8.65
		2708	48.30	34.79	6.31	10.60	3.42	66.08	4.68	1.21	7.68
		2714	46.73	36.86	4.94	11.47	3.89	62.96	5.22	1.08	10.44
		Average	47.46	35.29	5.69	11.56	3.51	64.20	4.94	1.17	8.92
		*2709	47.17	36.20	5.60	11.03	3.56	66.70	4.51	1.21	7.39
	Fourth	2710	45.06	37.09	5.24	12.61	4.20	63.97	4.93	1.03	8.32
		*2711	44.61	38.10	5.40	11.89	3.79	63.83	5.06	1.01	9.02
		2712	47.02	35.36	4.86	12.76	3.94	64.23	4.64	0.93	8.64
		2713	46.20	36.58	4.74	12.48	4.24	62.56	4.96	1.09	9.93
		Average	45.72	36.78	5.06	12.44	4.04	63.65	4.90	1.02	8.98
With Syphons	First	2716	47.18	34.98	5.39	12.45	3.69	63.03	4.69	1.20	9.55
		2719	46.73	35.39	4.91	12.97	4.54	63.66	4.72	1.06	8.14
		2724	47.25	34.39	4.98	13.38	3.48	63.18	4.93	1.00	9.05
		Average	47.05	34.93	5.09	12.93	3.90	63.29	4.78	1.09	8.91
	Second	*2715	47.51	35.07	5.70	11.72	3.65	64.36	4.72	1.17	8.68
		*2717	47.28	35.18	5.35	12.19	3.59	64.40	4.72	1.18	8.57
		*2720	48.32	35.54	4.90	11.24	3.38	66.49	4.63	1.21	8.15
		2725	47.67	36.19	4.85	11.29	3.76	65.14	4.92	1.16	8.88
		2728	48.47	34.53	5.82	11.18	3.66	64.59	4.94	0.95	8.86
		2729	47.84	35.12	5.29	11.75	3.58	64.32	4.93	0.92	9.21
		Average	47.85	35.27	5.32	11.56	3.61	64.88	4.81	1.10	8.73
	Third	2722	47.58	34.84	5.36	12.22	3.58	63.79	4.89	1.16	9.00
		2723	47.07	35.95	5.38	11.60	3.32	64.46	5.01	1.18	9.05
		*2727	48.96	34.33	5.40	11.31	3.15	65.32	4.86	0.92	9.04
		2731	47.50	34.69	5.20	12.61	3.34	63.16	5.04	0.95	9.70
		Average	47.78	34.94	5.34	11.94	3.35	64.18	4.95	1.05	9.20
	Fourth	2718	46.37	35.62	5.13	12.88	3.97	62.82	5.00	1.10	9.10
		2721	48.18	35.39	5.29	11.14	3.46	64.80	4.91	1.10	9.30
		*2726	46.39	35.89	4.69	13.03	3.82	64.13	4.79	1.20	8.34
		2730	48.69	35.21	5.38	10.72	3.16	66.02	4.85	0.94	8.93
		Average	47.41	35.53	5.12	11.94	3.60	64.44	4.89	1.09	8.92

*For the meaning of these asterisks see page 80.

TABLE 23
COAL AND AIR SUPPLY

General Test Conditions		Test Number	Approximate Thickness of Firebed, Inches		Coal Fired, Total	Dry Coal Fired, Total	Combustible by Analysis, Total	Carbon Burned per Pound Coal as Fired	Air Used	
With or Without Syphons	Rate of Evaporation		Start of Test	End of Test					Per Pound Carbon Burned	Per Pound Coal as Fired
				Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Code Item ☞			(149)	(149)	150	151	152	153		154
Without Syphons	First	2702	5	19	20 000	18 888	16 758	0.598	22.07	13.20
		2703	5	18	20 000	18 870	16 802	0.583	22.89	13.34
		2706	6.5	18	20 000	18 764	16 424	0.619	28.66	17.74
		Average	...	...	.....	.....	.....	0.600	24.54	14.76
	Second	2701	4	19	20 000	18 756	16 328	0.616	20.92	12.89
		2704	6	16	20 000	18 860	16 560	0.603	26.21	15.80
		2707	7	17.5	20 000	18 972	16 450	0.605	21.24	12.85
		Average	...	...	.....	.....	.....	0.608	22.79	13.85
	Third	2705	13	19	20 000	18 838	16 314	0.602	32.09	19.32
		2708	7.5	17	20 000	18 738	16 618	0.618	22.90	14.15
		2714	9	18.5	20 000	19 012	16 718	0.564	21.51	12.13
		Average	...	...	.....	.....	.....	0.595	28.83	15.20
		*2709	10	18	20 000	18 880	16 674	0.635	20.61	13.09
	Fourth	2710	9	18.5	20 000	18 952	16 430	0.566	19.21	10.87
		*2711	9	19	15 160	14 341	12 539	0.572	20.19	11.55
		2712	8	17.5	20 000	19 028	16 476	0.568	20.34	11.55
		2713	10.5	17	20 000	19 052	16 556	0.558	19.08	10.65
		Average	...	...	.....	.....	.....	0.566	19.71	11.16
With Syphons	First	2716	5	19	20 000	18 922	16 432	0.596	....	....
		2719	5	19.5	20 000	19 018	16 424	0.604	21.60	13.05
		2724	4.5	19.5	20 000	19 004	16 328	0.590	22.16	13.07
		Average	...	...	.....	.....	.....	0.597	21.88	13.06
	Second	*2715	5	18	10 082	9 507	8 328	0.593	24.50	14.53
		*2717	4	18	20 000	18 930	16 492	0.578	....	....
		*2720	5	19	18 635	17 722	15 627	0.620	20.78	12.88
		2725	5	18.5	20 000	19 030	16 772	0.610	20.04	12.22
		2728	5.5	18	20 000	18 836	16 600	0.583	22.13	12.90
		2729	5	18	20 000	18 942	16 592	0.597	23.06	13.77
		Average	...	...	.....	.....	.....	0.597	22.10	13.26
	Third	2722	5	18.5	20 000	18 928	16 484	0.574	21.54	12.36
		2723	6	19	20 000	18 924	16 604	0.573	20.83	11.94
		*2727	7	18	17 825	16 862	14 846	0.585	19.21	11.24
		2731	6	19	20 000	18 960	16 438	0.578	21.06	12.17
		Average	...	...	.....	.....	.....	0.578	20.66	11.93
	Fourth	2718	7	20	20 000	18 974	16 398	0.541	21.00	11.36
		2721	6	19	20 000	18 942	16 714	0.566	20.13	11.39
		*2726	7	18.5	17 700	16 870	14 564	0.544	18.85	10.25
		2730	7	18	20 000	18 924	16 780	0.575	19.94	11.47
		Average	...	...	.....	.....	.....	0.557	19.98	11.12

*For the meaning of these asterisks see page 80.

Table 24
Firing Rate, Smoke, and Gas Analysis

General Test Conditions			Coal as Fired			Dry Coal Fired			Analysis of Dry Smokebox Gases by Volume			
With or Without Syphons	Rate of Evaporation	Test Number	Per Hour	Per Square Foot of Grate Surface per Hour	Per Cubic Foot of Firebox Volume per Hour	Per Hour	Per Square Foot of Grate Surface per Hour	Percentage of Smoke Observed	Carbon Dioxide CO_2	Oxygen O_2	Carbon Monoxide CO	Nitrogen N_2
			Pounds	Pounds	Pounds	Pounds	Pounds	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Code Item ☞			155	156	157	158	159	160	161	162	163	164
Without Syphons	First	2702	2489.7	35.379	7.20	2351.4	33.41	29	10.74	6.99	0.37	81.90
		2703	2474.3	35.159	7.15	2334.5	33.17	26	10.63	7.34	0.21	81.82
		2706	2575.0	36.591	7.44	2415.9	34.33	49	8.51	9.59	0.14	81.76
		Average	2513.0	35.710	7.26	2367.3	33.64	35	9.96	7.97	0.24	81.83
	Second	2701	3592.6	51.050	10.38	3369.1	47.88	41	11.45	6.44	0.40	81.71
		2704	3669.7	52.146	10.61	3460.5	49.17	34	9.26	9.05	0.17	81.52
		2707	3703.7	52.639	10.71	3513.3	49.93	36	11.48	6.43	0.21	81.88
		Average	3655.3	51.945	10.57	3447.6	48.99	37	10.73	7.31	0.26	81.70
	Third	2705	5714.3	81.215	16.51	5382.3	76.50	54	7.50	10.99	0.22	81.29
		2708	5853.1	83.188	16.92	5483.7	77.94	41	10.74	6.59	0.18	82.49
		2714	5660.9	80.456	16.36	5381.3	76.48	36	11.38	6.66	0.15	81.81
		Average	5742.8	81.620	16.60	5415.8	76.97	44	9.87	8.08	0.18	81.87
		*2709	6666.7	94.751	19.26	6293.3	89.44	32	11.80	6.03	0.25	81.92
	Fourth	2710	7017.6	99.737	20.28	6649.8	94.51	38	12.46	4.87	0.51	82.16
		*2711	6890.9	97.938	19 92	6518.6	92.65	31	12.28	5.54	0.05	83.13
		2712	7017.5	99.737	20.28	6676.5	94.89	31	12.01	5.73	0.22	82.04
		2713	7017.5	99.737	20.28	6684.9	95.01	38	13.01	4.22	0.12	82.65
		Average	6985.9	99.287	20.19	6632.5	94.27	35	12.44	5.09	0.23	82.25
With Syphons	First	2716	2334.8	33.180	6.95	2209.0	31.40	24	.....	....	....	.....
		2719	2272.7	32.300	6.76	2161.0	30.70	31	11.36	7.05	0.08	81.51
		2724	2290.1	32.550	6.82	2176.0	30.92	26	11.09	7.63	0.03	81.25
		Average	2299.2	32.677	6.84	2182.0	31.01	27	11.23	7.34	0.06	81.38
	Second	*2715	3360.6	47.750	10.00	3169.0	45.03	26	10.10	7.48	0.09	82.33
		*2717	3438.8	48.870	10.24	3255.0	46.27	32	.....	....	....	.....
		*2720	3269.3	46.470	9.73	3109.0	44.18	23	11.84	6.46	0.07	81.63
		2725	3278.7	46.600	9.76	3120.0	44.35	24	12.23	6.16	0.11	81.50
		2728	3269.6	46.470	9.73	3279.0	43.76	43	11.08	7.31	0.09	81.52
		2729	3351.8	47.640	9.98	3174.0	45.11	34	10.64	7.83	0.07	81.46
		Average	3328.1	47.300	9.91	3151.0	44.78	30	11.18	7.05	0.08	81.49
	Third	2722	5105.9	72.570	15.20	4832.0	68.66	29	11.45	6.95	0.03	81.57
		2723	5194.8	73.830	15.46	4915.0	69.84	24	11.67	6.43	0.22	81.68
		*2727	4974.8	70.690	14.81	4706.0	66.88	25	12.87	5.37	0.03	81.73
		2731	5194.8	73.830	15.46	4925.0	69.99	38	11.67	6.79	0.06	81.48
		Average	5117.6	72.730	15.23	4844.5	68.84	29	11.92	6.39	0.09	81.62
	Fourth	2718	6451.6	91.690	19.20	6121.0	86.97	24	11.79	5.72	0.11	82.38
		2721	6383.7	90.730	19.00	6046.0	85.93	39	12.14	5.73	0.20	81.93
		*2726	6321.4	89.840	18.81	6025.0	85.62	27	12.97	4.53	0.26	82.24
		2730	6349.2	90.240	18.90	6007.0	85.38	58	12.35	5.93	0.07	81.65
		Average	6376.5	90.630	18.98	6049.8	85.98	37	12.31	5.48	0.16	82.05

*For the meaning of these asterisks see page 80.

Table 25
Ash and Cinders

General Test Conditions		Test Number	Ash Collected From Ashpan (Dry)	Ash on Grate at Close of Test (Dry)	Tota Ash (Dry)	Estimated Weight of Fire on Grate at Start of Test	Net Equivalent Ashpan Ash for Test	Net Equivalent Ash in Percentage of Total Dry Coal Fired	Ash by Analysis	Net Equivalent Ash for Test, Percentage of Ash by Analysis	Tota Cinders	Cinders in Per Cent of Tota Dry Coal Fired
With or Without Syphons	Rate of Evaporation		Pounds	Pounds	Pounds	Pounds	Pounds	Per Cent	Pounds	Per Cent	Pounds	Per Cent
Code Item ☞			165					166	167	168	171	172
Without Syphons	First	2702	1638	2098	3736	545	3191	16.9	2130	149.8	208.5	1.49
		2703	1462	2174	3636	609	3027	16.0	2068	146.4	296.0	1.57
		2706	422	3955	4377	1424	2951	15.7	2340	126.1	120.0	0.64
		Average	1174	2742	3916	859	3056	16.2	2179	140.8	232.2	1.23
	Second	2701	589	2720	3309	571	2738	14.6	2428	112.8	289.0	1.54
		2704	1158	2124	3282	786	2496	13.2	2300	108.6	348.0	1.85
		2707	796	2530	3326	1013	2313	12.2	2522	91.7	203.0	1.07
		Average	848	2458	3306	790	2516	13.3	2417	104.4	280.0	1.48
	Third	2705	770	2552	3322	1735	1587	8.4	2524	62.9	643.0	3.41
		2708	801	2017	2818	887	1931	10.3	2120	91.1	690.0	3.68
		2714	1315	2458	3773	1204	2569	13.5	2294	112.0	746.0	3.92
		Average	962	2342	3304	1275	2029	10.7	2313	88.7	693.0	3.67
		*2709	849	2247	3096	1258	1838	9.7	2206	83.3	293.0	1.55
	Fourth	2710	1003	2196	3199	1076	2123	11.2	2522	84.2	1335.0	7.04
		*2711	26	2678	2704	1259	1445	10.1	1803	80.1	826.0	5.76
		2712	1031	2853	3884	1312	2572	13.5	2552	100.8	1236.0	6.50
		2713	1134	2696	3830	1671	2159	11.3	2496	86.5	1201.0	6.30
		Average	799	2606	3404	1330	2075	11.5	2343	87.9	1150.0	6.40
With Syphons	First	2716	1585	1849	3434	481	2953	15.6	2490	118.6	374.0	1.98
		2719	912	2265	3177	589	2588	13.6	2594	99.8	283.0	1.49
		2724	1250	2258	3508	519	2989	15.7	2676	111.7	299.0	1.57
		Average	1249	2124	3373	530	2843	15.0	2587	110.0	318.7	1.68
	Second	*2715	723	1566	2289	438	1851	19.5	1182	156.6	222.0	2.34
		*2717	1595	2065	3660	454	3206	16.9	2438	131.5	548.5	2.90
		*2720	762	1860	2622	484	2138	12.1	2095	102.1	483.0	2.73
		2725	885	2735	3620	738	2882	15.1	2258	127.6	480.0	2.52
		2728	1021	2040	3061	632	2429	12.9	2236	108.6	592.0	3.14
		2729	882	2257	3139	632	2507	13.2	2350	106.7	555.0	2.93
		Average	978	2087	3065	563	2502	15.0	2093	122.2	480.1	2.76
	Third	2722	646	2610	3256	705	2551	13.5	2444	104.4	897.0	4.74
		2723	714	2840	3554	909	2645	14.0	2320	114.0	907.0	4.79
		*2727	578	1975	2553	770	1783	10.6	2016	88.4	935.0	5.55
		2731	908	2246	3154	719	2435	12.8	2522	96.6	1010.0	5.33
		Average	712	2418	3129	776	2354	12.7	2326	100.9	937.3	5.10
	Fourth	2718	730	2789	3719	976	2743	14.6	2576	106.5	1320.5	6.96
		2721	443	2742	3185	850	2335	12.3	2228	104.8	1417.0	7.48
		*2726	694	2240	2934	851	2083	12.3	2306	90.3	1260.0	7.47
		2730	462	2307	2769	900	1869	9.9	2144	87.2	1546.0	8.17
		Average	582	2520	3152	894	2260	12.3	2314	97.2	1385.9	7.52

*For the meaning of these asterisks see page 80.

Table 26
Analysis of Ash and Cinders

General Test Conditions		Test Number	Analysis of Ash Collected from Ashpan		Analysis of Ash on Grate at Close of Test		Analysis of Cinders			
With or Without Syphons	Rate of Evaporation		Carbon Per Cent	Ash Per Cent	Carbon Per Cent	Ash Per Cent	Volatile Matter Per Cent	Carbon Per Cent	Ash Per Cent	Moisture Per Cent
Code Item ☞			173	174				176	177	178
Without Syphons	First	2702	43.03	56.97	46.89	53.11	5.89	52.75	40.56	0.80
		2703	43.31	56.69	44.66	55.34	5.85	48.75	44.48	0.92
		2706	14.45	85.55	31.86	68.14	5.85	52.05	41.64	0.46
		Average	33.60	66.40	41.14	58.86	5.86	51.18	42.23	0.73
	Second	2701	21.72	78.28	22.64	77.36	8.22	42.73	48.55	0.50
		2704	22.34	77.66	45.33	54.67	6.11	49.63	43.94	0.32
		2707	26.35	73.65	37.47	62.53	5.10	55.64	38.91	0.35
		Average	23.47	76.53	35.15	64.85	6.48	49.33	43.80	0.39
	Third	2705	21.46	78.54	27.99	72.01	5.73	51.98	42.23	0.06
		2708	22.66	77.34	40.74	59.26	5.28	61.98	31.94	0.80
		2714	32.10	67.90	32.15	67.85	2.33	65.77	31.83	0.07
		Average	25.41	74.59	33.63	66.37	4.45	59.91	35.33	0.31
		*2709	25.97	74.03	24.31	75.69	5.99	57.18	36.82	0.01
	Fourth	2710	33.29	66.71	36.14	63.86	4.43	57.57	37.95	0.05
		*2711	30.74	69.26	37.55	62.45	4.02	67.89	27.90	0.19
		2712	23.91	76.09	36.63	63.37	4.02	70.62	25.35	0.01
		2713	24.16	75.84	46.69	53.31	3.32	68.18	28.43	0.07
		Average	28.03	71.97	39.25	60.75	3.95	66.07	29.91	0.08
With Syphons	First	2716	18.71	81.29	28.02	71.98	6.58	36.88	56.12	0.42
		2719	20.16	79.84	25.81	74.19	6.20	44.15	49.16	0.49
		2724	23.50	76.50	26.05	73.95	5.78	43.68	50.12	0.42
		Average	20.79	79.21	26.63	73.37	6.19	41.57	51.80	0.44
	Second	*2715	22.22	77.78	23.64	76.36	7.92	45.49	46.22	0.37
		*2717	33.38	66.62	30.40	69.60	5.80	44.43	49.37	0.40
		*2720	26.12	73.88	28.51	71.49	3.49	57.18	39.22	0.11
		2725	28.31	71.69	28.04	71.96	4.18	56.63	39.13	0.06
		2728	40.40	59.60	27.32	72.68	4.82	47.73	47.19	0.26
		2729	23.95	76.05	36.31	63.69	3.93	58.49	37.44	0.14
		Average	29.06	70.94	29.04	70.96	5.02	51.66	43.10	0.22
	Third	2722	26.80	73.20	26.02	73.98	3.36	67.04	29.45	0.15
		2723	30.67	69.33	32.26	67.74	3.33	68.37	28.30	0.00
		*2727	34.47	65.53	28.09	71.91	4.32	64.03	31.62	0.03
		2731	30.51	69.49	22.01	77.99	3.26	71.55	25.17	0.02
		Average	30.61	69.39	27.10	72.90	3.57	67.75	28.64	0.05
	Fourth	2718	31.09	68.91	32.03	67.97	3.96	67.34	28.69	0.01
		2721	28.15	71.85	23.90	76.10	3.98	68.59	27.38	0.05
		*2726	38.71	61.29	29.02	70.98	3.07	72.05	24.87	0.01
		2730	31.52	68.48	24.51	75.49	3.10	71.95	24.94	0.01
		Average	32.37	67.63	27.37	72.63	3.53	69.98	26.47	0.02

*For the meaning of these asterisks see page 80.

Table 27
Quality of Steam, Superheat, and Evaporation

General Test Conditions		Test Number	Quality of Steam in Dome	Degrees of Superheat, Fahrenheit		Water Delivered to Boiler, Total	Weight of Water in Boiler at Start of Test, Less Weight at Close of Test	Correction for Difference in Boiler Pressure at Start and Close of Test	Boiler Correction	Moist Steam Evaporated	
With or Without Syphons	Rate of Evaporation			In Branch Pipe	In Exhaust Passage					Total	Per Hour
						Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Code Item ☞			179	180	181	182	188	(188a)	189		201
Without Syphons	First	2702	0.9748	187.2	30.1	135 029	−1131	+397	− 734	134 295	16 718
		2703	0.9744	184.2	31.5	132 262	− 668	+241	− 427	131 835	16 310
		2706	0.9793	170.0	24.7	130 983	− 843	+255	− 588	130 395	16 788
		Average	0.9762	180.5	28.8	.....	.....	.....	.....	132 176	16 605
	Second	2701	0.9769	208.5	30.4	132 467	− 9	− 10	− 19	132 448	23 792
		2704	0.9786	196.0	25.8	133 975	+ 18	+ 18	+ 36	134 011	24 589
		2707	0.9812	196.3	31.5	130 932	− 944	+239	− 705	130 227	24 116
		Average	0.9789	200.3	29.2	.....	.....	.....	.....	132 229	24 166
	Third	2705	0.9784	233.3	....	123 829	− 258	− 23	− 281	123 548	35 299
		2708	0.9790	229.9	61.7	123 990	−1306	+440	− 866	123 124	36 033
		2714	0.9768	247.2	73.4	128 351	−2316	+688	−1642	126 709	35 864
		Average	0.9781	236.8	67.6	.....	.....	.....	.....	124 467	35 732
		*2709	0.9799	252.4	87.8	120 546	+ 111	−104	+ 7	120 553	40 184
	Fourth	2710	0.9774	265.7	104.2	120 920	+ 203	− 26	+ 177	121 097	42 490
		*2711	0.9779	260.7	100.2	92 952	− 380	+ 87	− 293	92 659	42 118
		2712	0.9766	259.2	101.6	119 704	−1541	+442	−1099	118 605	41 616
		2713	0.9739	258.0	93.6	118 948	+ 41	+ 35	+ 76	119 024	41 763
		Average	0.9765	260.9	99.9	.....	.....	.....	.....	112 846	41 997
With Syphons	First	2716	0.9765	162.1	28.2	143 378	− 29	− 16	− 45	143 333	16 731
		2719	0.9734	162.6	19.0	146 978	+ 5	+ 4	+ 9	146 987	16 703
		2724	0.9845	155.8	20.2	140 060	+ 4	+ 4	+ 8	146 068	16 726
		Average	0.9781	160.2	22.5	.....	.....	.....	.....	145 463	16 720
	Second	*2715	0.9779	198.3	32.2	68 566	+1147	−362	+ 785	67 781	22 594
		*2717	0.9748	199.5	29.7	136 732	+ 328	−110	+ 218	136 950	23 543
		*2720	0.9734	197.1	26.2	135 815	+1156	−250	+ 906	136 721	23 986
		2725	0.9850	192.4	27.0	144 116	+ 660	−160	+ 500	144 666	23 716
		2728	0.9763	194.8	27.2	143 055	+1247	−300	+ 947	144 002	23 541
		2729	0.9762	189.3	26.2	141 144	+ 399	−101	+ 298	141 442	23 704
		Average	0.9773	195.2	28.1	.....	.....	.....	.....	128 594	23 514
	Third	2722	0.9761	246.5	72.7	137 600	− 215	+ 55	− 160	137 440	35 088
		2723	0.9694	240.4	71.5	135 139	+ 95	−141	− 46	135 093	35 089
		*2727	0.9790	240.7	72.7	124 220	+ 609	−133	+ 476	124 696	34 802
		2731	0.9763	244.9	73.7	132 654	+ 381	−117	+ 264	132 918	34 524
		Average	0.9752	243.1	72.7	.....	.....	.....	.....	132 537	34 876
	Fourth	2718	0.9756	255.2	96.2	126 197	− 44	− 43	− 87	126 110	40 681
		2721	0.9767	266.1	101.1	129 471	+ 187	−386	− 199	129 272	41 262
		*2726	0.9780	252.6	92.4	114 438	− 210	+ 69	− 141	114 297	40 820
		2730	0.9725	259.2	98.1	127 980	+ 201	− 64	+ 137	128 117	40 672
		Average	0.9757	258.3	97.0	.....	.....	.....	.....	124 449	40 859

*For the meaning of these asterisks see page 80.

Table 28
Heat Transfer

General Test Conditions		Test Number	Moist Steam Used by Auxiliaries, etc.	Steam to Superheater		Heat Transfer in Units of Evaporation (1000 B.t.u.) per Hour				Units of Evaporation per Pound of Coal	
With or Without Syphons	Rate of Evaporation			Total	Per Hour	Across Water Heating Surface	Across Superheating Surface	Across Total Heating Surface	Per Square Foot of Combined Heating Surface (Average)	As Fired	Dry Coal
			Pounds	Pounds	Pounds						
Code Item ☞			190		192	194	195	196	197	198	199
Without Syphons	First	2702	401	133 497	16 619	19 042	2117	21 159	4.46	8.50	9.00
		2703	226	131 368	16 252	18 592	2051	20 643	4.36	8.34	8.84
		2706	726	129 414	16 662	19 172	1918	21 090	4.44	8.18	8.73
		Average	...	.....	16 511	18 935	2029	20 964	4.42	8.34	8.86
	Second	2701	31	132 427	23 788	27 168	3233	30 401	6.41	8.46	9.02
		2704	13	133 980	24 584	28 120	3152	31 272	6.60	8.52	9.03
		2707	...	129 988	24 072	27 625	3038	30 663	6.46	8.28	8.73
		Average	...	.....	24 148	27 638	3141	30 779	6.49	8.42	8.93
	Third	2705	168	123 404	35 258	40 347	5179	45 526	9.60	7.96	8.46
		2708	...	122 684	35 904	41 236	5195	46 431	9.79	7.94	8.47
		2714	...	126 035	35 674	40 978	5529	46 508	9.81	8.22	8.64
		Average	...	.....	35 612	40 854	5301	46 155	9.73	8.04	8.52
		*2709	78	120 579	40 193	46 015	6322	52 337	11.04	7.85	8.31
	Fourth	2710	90	121 033	42 468	48 587	6961	55 548	11.71	7.92	8.35
		*2711	...	92 572	42 078	48 137	6749	54 886	11.57	7.96	8.42
		2712	...	118 163	41 461	47 584	6663	54 247	11.44	7.73	8.13
		2713	...	118 989	41 751	47 656	6780	54 436	11.48	7.75	8.15
		Average	...	.....	41 940	47 991	6788	54 779	11.55	7.84	8.26
With Syphons	First	2716	...	143 349	16 733	19 045	1889	20 934	4.37	8.96	9.48
		2719	...	146 983	16 703	18 986	1944	20 931	4.37	9.21	9.68
		2724	...	146 064	16 726	19 160	1731	20 891	4.36	9.12	9.60
		Average	...	.....	16 721	19 064	1855	20 919	4.37	9.10	9.59
	Second	*2715	...	69 713	23 238	25 814	3014	28 828	6.01	8.58	9.10
		*2717	...	137 060	23 562	26 834	3138	29 973	6.25	8.71	9.21
		*2720	...	136 971	24 030	27 277	3206	30 482	6.35	9.32	9.81
		2725	...	144 776	23 734	27 226	2877	30 103	6.28	9.18	9.64
		2728	...	144 302	23 590	26 886	3055	29 941	6.24	9.16	9.72
		2729	...	141 543	23 721	27 075	3008	30 083	6.27	8.97	9.48
		Average	...	.....	23 646	26 852	3050	29 902	6.23	8.99	9.49
	Third	2722	16	137 369	35 070	40 088	5460	45 548	9.50	8.92	9.43
		2723	101	135 133	35 100	39 921	5553	45 474	9.48	8.75	9.26
		*2727	...	124 829	34 839	39 803	5233	45 036	9.39	9.05	9.57
		2731	...	133 035	34 555	39 475	5325	44 800	9.34	8.63	9.10
		Average	...	.....	34 891	39 822	5393	45 215	9.43	8.84	9.34
	Fourth	2718	...	126 153	40 695	46 568	6597	53 164	11.08	8.24	8.68
		2721	20	129 638	41 378	47 195	6782	53 977	11.25	8.45	8.93
		*2726	...	114 228	40 796	46 706	6364	53 070	11.06	8.39	8.81
		2730	...	128 181	40 692	46 451	6661	53 113	11.07	8.36	8.84
		Average	...	.....	40 890	46 730	6601	53 331	11.12	8.36	8.82

*For the meaning of these asterisks see page 80.

TABLE 29
EQUIVALENT EVAPORATION

General Test Conditions		Test Number	Equivalent Evaporation, Pounds			
With or Without Syphons	Rate of Evaporation		Per Hour	Per Pound of Coal as Fired	Per Pound of Dry Coal	Per Square Foot of Combined Heating Surface
Code Item ☞						
Without Syphons	First	2702	21 809	8.76	9.28	4.60
		2703	21 277	8.60	9.11	4.49
		2706	21 737	8.44	9.00	4.58
		Average	21 608	8.60	9.13	4.56
	Second	2701	31 334	8.72	9.30	6.61
		2704	32 232	8.78	9.31	6.80
		2707	31 604	8.53	9.00	6.66
		Average	31 723	8.68	9.20	6.69
	Third	2705	46 924	8.21	8.72	9.89
		2708	47 857	8.18	8.73	10.09
		2714	47 935	8.47	8.91	10.11
		Average	47 572	8.29	8.79	10.03
		*2709	53 944	8.09	8.57	11.38
	Fourth	2710	57 253	8.16	8.61	12.07
		*2711	56 571	8.21	8.68	11.93
		2712	55 912	7.97	8.38	11.79
		2713	56 107	7.99	8.39	11.83
		Average	56 461	8.08	8.52	11.91
With Syphons	First	2716	21 577	9.24	9.77	4.50
		2719	21 573	9.49	9.98	4.50
		2724	21 532	9.40	9.90	4.49
		Average	21 561	9.38	9.88	4.50
	Second	*2715	29 713	8.84	9.38	6.19
		*2717	30 893	8.98	9.49	6.44
		*2720	31 418	9.61	10.11	6.55
		2725	31 027	9.46	9.94	6.47
		2728	30 860	9.44	10.02	6.43
		2729	31 006	9.25	9.77	6.46
		Average	30 819	9.26	9.79	6.42
	Third	2722	46 947	9.19	9.72	9.79
		2723	46 870	9.02	9.54	9.77
		*2727	46 418	9.33	9.86	9.68
		2731	46 175	8.89	9.38	9.63
		Average	46 603	9.11	9.63	9.72
	Fourth	2718	54 796	8.49	8.95	11.42
		2721	55 634	8.71	9.20	11.60
		*2726	54 700	8.65	9.08	11.40
		2730	54 743	8.62	9.11	11.41
		Average	54 968	8.62	9.09	11.46

*For the meaning of these asterisks see page 80.

Table 30
Actual Evaporation and Heat Transfer

General Test Conditions			Superheated Steam (Steam to Engine)				Coal Fired Equivalent to Steam Used by		B.t.u. Transferred to Boiler per Pound of Coal as Fired	B.t.u. Transferred to Boiler per Pound of Dry Coal
With or Without Syphons	Rate of Evaporation	Test Number	Per Hour	Per Pound Coal as Fired	Per Pound of Dry Coal	Per Square Foot of Heating Surface per Hour	Engine	Auxiliaries		
			Pounds	Pounds	Pounds	Pounds	Pounds	Pounds		
Code Item ☞			200 = 215	202	203	204	216	217		
Without Syphons	First	2702	16 619	6.67	7.07	3.50	2483	7	8498	9000
		2703	16 252	6.57	6.96	3.43	2470	4	8344	8841
		2706	16 662	6.47	6.90	3.51	2562	13	8190	8729
		Average	16 511	6.57	6.98	3.48	2505	..	8344	8857
	Second	2701	23 788	6.62	7.06	5.02	3593	0	8461	9024
		2704	24 584	6.70	7.10	5.18	3670	0	8521	9035
		2707	24 072	6.50	6.85	5.08	3704	0	8278	8728
		Average	24 148	6.61	7.00	5.09	3655	..	8420	8929
	Third	2705	35 258	6.17	6.55	7.43	5707	7	7967	8459
		2708	35 904	6.13	6.55	7.57	5853	0	7933	8467
		2714	35 674	6.30	6.63	7.52	5661	0	8215	8643
		Average	35 612	6.20	6.58	7.51	5740	..	8038	8523
		*2709	40 193	6.03	6.39	8.48	6663	4	7850	8317
	Fourth	2710	42 468	6.05	6.39	8.96	7018	0	7915	8353
		*2711	42 078	6.11	6.45	8.87	6891	0	7965	8419
		2712	41 461	5.91	6.21	8.74	7018	0	7730	8126
		2713	41 751	5.95	6.25	8.80	7018	0	7757	8143
		Average	41 940	6.01	6.33	8.84	6986	..	7842	8260
With Syphons	First	2716	16 733	7.17	7.57	3.49	2335	0	8965	9477
		2719	16 703	7.35	7.73	3.48	2273	0	9208	9686
		2724	16 726	7.30	7.69	3.49	2290	0	9123	9601
		Average	16 721	7.27	7.66	3.49	2300	..	9099	9588
	Second	*2715	23 238	6.91	7.33	4.84	3361	0	8577	9097
		*2717	23 562	6.85	7.24	4.91	3439	0	8715	9208
		*2720	24 030	7.35	7.73	5.01	3269	0	9325	9805
		2725	23 734	7.24	7.61	4.95	3279	0	9180	9648
		2728	23 590	7.21	7.66	4.92	3270	0	9156	9724
		2729	23 721	7.08	7.47	4.94	3352	0	8975	9478
		Average	23 646	7.11	7.51	4.93	3328	..	8988	9493
	Third	2722	35 070	6.87	7.26	7.31	5106	0	8920	9426
		2723	35 100	6.76	7.14	7.32	5192	3	8753	9252
		*2727	34 839	7.00	7.40	7.26	4975	0	9052	9570
		2731	34 555	6.65	7.02	7.20	5195	0	8624	9096
		Average	34 891	6.82	7.21	7.27	5117	..	8837	9336
	Fourth	2718	40 695	6.31	6.65	8.48	6452	0	8240	8686
		2721	41 378	6.48	6.84	8 63	6384	0	8455	8928
		*2726	40 796	6.45	6.77	8.50	6321	0	8396	8808
		2730	40 692	6.41	6.77	8.48	6349	0	8366	8842
		Average	40 890	6.41	6.76	8.52	6377	..	8364	8816

*For the meaning of these asterisks see page 80.

Table 31
Heat Distribution

General Test Conditions		Test Number	Efficiency of Boiler and Furnace = Per Cent of Heat in Coal Fired Transferred to Water	Loss of Heat Due to							
With or Without Syphons	Rate of Evaporation			Moisture in Coal	Moisture in Air	Hydrogen Content of Coal	Sensible Heat in Escaping Gases	Thermal Value of Combustible in Escaping Gases	B.t.u. in Cinders	B.t.u. in Ash	Radiation and Unaccounted for
				Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
Code Item ☞			206	207	208	209	210	211	212	213	214
Without Syphons	First	2702	70.14	0.58	0.23	4.12	12.03	1.68	0.86	8.16	2.20
		2703	68.77	0.59	0.12	4.79	11.97	0.95	0.89	7.78	4.14
		2706	68.65	0.64	0.39	4.68	15.06	0.85	0.37	2.57	6.79
		Average	69.19	0.60	0.25	4.53	13.02	1.16	0.71	6.17	4.37
	Second	2701	71.73	0.67	0.20	4.39	12.76	1.77	0.78	3.63	4.07
		2704	71.06	0.60	0.14	5.01	14.74	0.92	1.07	3.35	3.11
		2707	69.50	0.53	0.34	4.72	11.29	0.93	0.73	3.69	8.27
		Average	70.76	0.60	0.23	4.71	12.93	1.21	0.86	3.56	5.14
	Third	2705	67.62	0.63	0.28	4.81	19.33	1.48	2.37	2.08	1.40
		2708	65.59	0.66	0.41	4.40	13.52	0.86	2.49	2.61	9.46
		2714	69.72	0.53	0.42	5.03	11.88	0.63	2.96	5.04	3.79
		Average	67.64	0.61	0.37	4.75	14.91	0.99	2.61	3.24	4.88
		*2709	64.83	0.59	0.25	4.26	12.83	1.11	1.04	2.84	12.25
	Fourth	2710	67.26	0.57	0.33	4.82	11.32	1.92	5.24	4.33	4.21
		*2711	66.88	0.58	0.35	4.85	11.70	0.20	4.59	3.54	7.31
		2712	65.76	0.53	0.31	4.54	11.96	0.88	5.42	3.77	6.83
		2713	66.74	0.52	0.28	4.86	10.80	0.44	5.04	3.23	8.09
		Average	66.66	0.55	0.32	4.77	11.45	0.86	5.07	3.72	6.60
With Syphons	First	2716	76.93	0.57	....	4.43	.....	....	1.04	3.42	....
		2719	78.13	0.51	0.22	4.44	11.05	0.36	0.70	3.19	1.40
		2724	77.80	0.52	0.25	4.63	10.85	0.14	0.83	4.32	0.66
		Average	77.62	0.53	0.24	4.50	10.95	0.25	0.86	3.64	1.03
	Second	*2715	72.72	0.61	0.29	4.54	13.40	0.45	1.27	4.99	1.73
		*2717	73.75	0.57	....	4.53	.....	....	1.70	6.52	....
		*2720	77.16	0.50	0.25	4.29	11.30	0.31	1.79	3.57	0.83
		2725	76.26	0.50	0.26	4.55	10.59	0.44	1 62	4.88	0.90
		2728	76.55	0.61	0.26	4.64	11.60	0.40	1.81	5.91	−1.78
		2729	75.51	0.56	0.24	4.68	12.81	0.33	1.82	3.64	0.41
		Average	75.33	0.56	0.26	4.54	11.94	0.39	1.67	4.92	0.42
	Third	2722	75.61	0.58	0.23	4.79	12.96	0.13	3.74	4.17	−2.21
		2723	73.26	0.58	0.21	4.87	12.43	0.90	3.43	4.89	−0.57
		*2727	75.56	0.57	0.33	4.61	10.99	0.11	4.20	4.15	−0.52
		2731	73.47	0.56	0.34	4.90	12.34	0.25	3.88	4.56	−0.30
		Average	74.48	0.57	0.28	4.79	12.18	0.35	3.81	4.44	−0.90
	Fourth	2718	70.10	0.56	0.18	4.92	11.88	0.43	5.21	5.22	1.50
		2721	70.46	0.57	0.23	4.79	12.42	0.78	5.78	3.94	1.03
		*2726	70.85	0.50	0.28	4.60	10.21	0.93	5.89	5.54	1.20
		2730	69.23	0.57	0.27	4.65	12.05	0.27	6.62	3.51	2.83
		Average	70.16	0.55	0.24	4.74	11.64	0.60	5.88	4.55	1.64

*For the meaning of these asterisks see page 80.

TABLE 32
INDICATOR DATA

General Test Conditions		Test Number	Indicated Horsepower					Averages of Events and Pressures					
			Right Side		Left Side			Pressures, Pounds per Square Inch					
With or Without Syphons	Rate of Evaporation		Head End	Crank End	Head End	Crank End	Total	Steam Chest Pressure	Initial Pressure	Pressure at Cut-off	Least Back Pressure	Mean Effective Pressure	Cut-off, Per Cent
Code Item ☞			225	226	227	228	224	220	221	222	223	218	219
Without Syphons	First	2702	211.40	224.40	224.00	224.90	884.7	184.7	180.0	131.8	2.06	65.79	24.7
		2703	210.95	250.76	222.72	238.23	922.7	185.0	179.9	133.5	3.56	66.96	24.8
		2706	222.90	236.50	226.56	242.40	928.3	191.6	181.6	135.7	5.44	67.37	24.8
		Average	.....	.....	.....	.....	911.9	187.1	180.5	133.7	3.69	66.71	24.8
	Second	2701	343.68	391.05	340.30	370.05	1445.1	.....	172.2	120.9	4.48	69.72	32.0
		2704	344.51	371.95	359.80	369.90	1446.2	181.3	177.5	122.4	6.79	70.00	32.4
		2707	339.00	361.20	344.10	361.00	1405.3	177.5	174.6	127.6	8.20	68.00	29.5
		Average	.....	.....	.....	.....	1432.2	179.4	174.8	123.6	6.49	69.24	31.3
	Third	2705	520.40	462.10	491.80	466.00	1940.3	178.4	172.5	139.3	15.10	95.47	45.9
		2708	479.60	465.00	479.70	473.00	1897.2	.....	171.6	133.7	13.50	92.07	46.5
		2714	496.90	493.70	482.70	487.40	1960.7	176.6	173.6	134.6	11.84	94.82	47.4
		Average	.....	.....	.....	.....	1932.7	177.5	172.6	135.9	13.48	94.12	46.6
		*2709	534.30	547.20	544.80	538.00	2164.3	174.7	166.0	120.3	17.20	78.40	47.5
	Fourth	2710	566.00	559.70	549.30	569.80	2244.8	175.7	161.3	114.8	18.40	72.40	47.8
		*2711	562.50	568.70	534.00	556.70	2221.9	179.3	162.1	114.1	18.80	71.40	47.9
		2712	551.30	553.50	557.50	579.20	2241.6	174.3	161.0	113.6	19.32	72.30	48.0
		2713	558.40	565.50	568.60	583.40	2276.0	175.0	161.4	113.6	17.31	73.51	48.3
		Average	.....	.....	.....	.....	2246.1	176.1	161.5	114.0	18.46	72.40	48.0
With Syphons	First	2716	206.60	234.60	217.80	232.70	891.7	178.4	176.6	130.6	1.18	64.75	24.8
		2719	206.30	239.70	221.20	234.50	901.7	182.0	179.6	134.2	1.70	65.45	24.4
		2724	204.50	233.50	218.00	227.40	883.4	177.1	179.5	134.2	1.70	64.10	23.8
		Average	.....	.....	.....	.....	892.3	179.2	178.6	133.0	1.53	64.77	24.3
	Second	*2715	331.70	360.30	344.30	356.50	1392.8	176.7	172.1	122.0	3.60	67.37	30.8
		*2717	307.40	347.20	342.60	363.90	1361.1	175.0	173.0	122.9	3.80	65.85	30.0
		*2720	324.90	364.30	348.70	367.10	1405.0	174.7	175.1	127.4	3.80	68.00	29.2
		2725	316.30	354.30	348.30	359.00	1377.9	173.1	175.1	124.0	4.30	66.70	30.0
		2728	324.40	348.50	337.80	343.60	1354.3	173.8	172.7	120.3	4.60	65.55	30.0
		2729	325.10	353.20	345.40	351.00	1374.7	177.2	174.6	121.2	4.70	66.50	30.3
		Average	.....	.....	.....	.....	1377.6	175.1	173.8	123.0	4.13	66.66	30.1
	Third	2722	481.78	492.98	482.16	480.21	1937.1	170.8	173.9	131.9	9.80	93.70	47.5
		2723	482.40	493.60	487.30	485.10	1948.4	167.0	173.9	132.4	9.40	94.30	46.1
		*2727	481.90	489.50	491.40	484.70	1947.7	167.5	173.5	132.6	9.80	94.10	45.9
		2731	480.14	484.66	490.10	470.64	1925.5	167.0	163.7	129.0	10.40	92.94	47.6
		Average	.....	.....	.....	.....	1939.7	168.1	171.3	131.5	9.85	93.76	46.8
	Fourth	2718	525.80	549.40	562.50	551.70	2189.4	168.0	158.1	112.0	16.90	71.40	46.4
		2721	535.30	564.50	563.90	553.30	2217.0	161.3	160.9	112.8	16.60	71.55	46.5
		*2726	525.70	542.80	554.50	549.00	2171.9	162.3	159.5	112.7	16.50	70.10	46.0
		2730	528.40	551.10	562.00	539.00	2180.5	163.8	159.9	111.7	16.75	70.31	45.7
		Average	.....	.....	.....	.....	2189.7	163.9	159.6	112.3	16.69	70.84	46.2

*For the meaning of these asterisks see page 80.

Table 33
Engine and Locomotive Performance

General Test Conditions		Test Number	Coal, Pounds per Indicated Horsepower-hour			B.t.u. of Coal Fired per Indicated Horsepower-hour	Steam per Indicated Horsepower-hour	Moist and Superheated Steam per Indicated Horsepower-hour	Tractive Effort Based on Mean Effective Pressure	Average Drawbar Pull	Drawbar Horsepower
With or Without Syphons	Rate of Evaporation		Coal as Fired	Dry Coal	Coal as Fired, Including Auxiliaries		Pounds	Pounds	Pounds	Pounds	
Code Item ☞			229	230	231	233	232	234		237	236
Without Syphons	First	2702	2.81	2.65	2.81	34 046	18.78	18.84	23 136	18 578	710.5
		2703	2.68	2.53	2.68	32 516	17.61	17.64	24 142	17 752	678.9
		2706	2.76	2.59	2.77	32 927	17.95	18.05	24 288	17 091	653.2
		Average	2.75	2.59	2.75	33 163	18.11	18.18	23 855	17 807	680.9
	Second	2701	2.49	2.33	2.49	29 370	16.46	16.46	25 126	20 638	1187.2
		2704	2.54	2.39	2.54	30 457	17.00	17.00	25 230	19 557	1120.9
		2707	2.64	2.50	2.64	31 442	17.13	17.13	24 518	19 016	1089.9
		Average	2.56	2.41	2.56	30 423	16.86	16.86	24 958	19 737	1132.7
	Third	2705	2.94	2.77	2.94	34 639	18.17	18.19	33 836	28 438	1630.6
		2708	3.09	2.89	3.09	37 374	18.92	18.92	33 208	28 131	1607.0
		2714	2.89	2.74	2.89	34 053	18.19	18.19	34 213	30 018	1720.4
		Average	2.97	2.80	2.97	35 355	18.43	18.43	33 752	28 862	1652.7
		*2709	3.08	2.91	3.08	37 253	18.57	18.58	28 245	22 109	1693.5
	Fourth	2710	3.13	2.96	3.13	36 834	18.92	18.92	26 131	21 288	1829.9
		*2711	3.10	2.93	3.10	36 921	18.94	18.94	25 754	20 601	1777.4
		2712	3.13	2.98	3.13	36 790	18.50	18.50	26 068	21 218	1825.0
		2713	3.08	2.94	3.08	35 799	18.34	18.34	26 445	21 842	1879.8
		Average	3.11	2.95	3.11	36 586	18.68	18.68	26 100	21 237	1828.0
With Syphons	First	2716	2.62	2.48	2.62	30 531	18.77	18.77	23 346	17 713	677.0
		2719	2.52	2.40	2.52	29 698	18.52	18.52	23 597	17 696	676.3
		2724	2.59	2.46	2.59	30 370	18.93	18.93	23 116	17 619	673.4
		Average	2.58	2.45	2.58	30 200	18.74	18.74	23 353	17 676	675.6
	Second	*2715	2.41	2.28	2.41	28 424	16.68	16.68	24 309	19 314	1107.0
		*2717	2.53	2.39	2.53	29 897	17.31	17.31	23 744	19 834	1136.8
		*2720	2.33	2.21	2.33	28 160	17.10	17.10	24 497	19 119	1096.3
		2725	2.38	2.27	2.38	28 648	17.22	17.22	24 037	19 208	1101.4
		2728	2.41	2.27	2.41	28 826	17.42	17.42	23 639	18 229	1044.8
		2729	2.44	2.31	2.44	29 002	17.26	17.26	23 974	19 921	1141.7
		Average	2.42	2.29	2.42	28 826	17.17	17.17	24 033	19 271	1104.7
	Third	2722	2.64	2.49	2.64	31 144	18.10	18.10	33 794	28 688	1644.2
		2723	2.67	2.52	2.67	31 901	18.01	18.02	34 003	.....	.....
		*2727	2.55	2.42	2.55	30 549	17.89	17.89	33 961	29 804	1709.8
		2731	2.70	2.56	2.70	31 693	17.95	17.95	33 522	30 273	1739.1
		Average	2.64	2.50	2.64	31 322	17.99	17.99	33 820	29 588	1697.7
	Fourth	2718	2.95	2.80	2.95	34 674	18.59	18.59	25 461	20 229	1739.4
		2721	2.88	2.73	2.88	34 557	18.66	18.66	25 796	21 333	1833.2
		*2726	2.91	2.77	2.91	34 486	18.78	18.78	25 251	19 919	1713.2
		2730	2.91	2.75	2.91	35 164	18.66	18.66	25 377	20 172	1733.9
		Average	2.91	2.76	2.91	34 720	18.67	18.67	25 471	20 413	1754.9

*For the meaning of these asterisks see page 80.

TABLE 34
LOCOMOTIVE PERFORMANCE AND EFFICIENCY

General Test Conditions		Test Number	Coal per Drawbar Horsepower-hour		Moist and Superheated Steam per Drawbar Horsepower-hour	B.t.u. Consumed by Engine per Drawbar Horsepower-hour	Locomotive Friction		Mechanical Efficiency of Locomotive	Efficiency = B.t.u. in Coal Converted to Work at Drawbar
With or Without Syphons	Rate of Evaporation		As Fired	Dry Coal			Friction Horsepower	Friction Expressed as Pull at Drawbar		
			Pounds	Pounds	Pounds			Pounds	Per Cent	Per Cent
Code Item ☞			238	239	240	241	243	244	245	246
Without Syphons	First	2702	3.50	3.31	23.46	42 406	174.2	4557	80.71	6.00
		2703	3.64	3.44	23.98	44 164	243.8	6378	73.58	5.76
		2706	3.94	3.70	25.65	47 004	275.1	7197	70.37	5.41
		Average	3.69	3.48	24.36	44 525	231.0	6044	74.89	5.72
	Second	2701	3.03	2.84	20.04	35 739	257.9	4483	82.15	7.12
		2704	3.27	3.09	21.93	39 211	325.3	5676	77.51	6.49
		2707	3.40	3.22	22.09	40 494	315.4	5503	77.56	6.28
		Average	3.23	3.05	21.35	38 481	299.5	5221	79.07	6.63
	Third	2705	3.50	3.30	21.65	41 237	309.7	5402	84.04	6.17
		2708	3.64	3.41	22.34	44 026	290.2	5081	84.70	5.78
		2714	3.29	3.13	20.74	38 766	240.3	4192	87.74	6.56
		Average	3.48	3.28	21.58	41 343	280.1	4892	85.49	6.17
		*2709	3.94	3.72	23.75	47 709	470.8	6146	78.25	5.33
	Fourth	2710	3.84	3.63	23.21	45 189	414.9	4828	81.52	5.63
		*2711	3.88	3.67	23.67	46 211	444.5	5152	79.99	5.50
		2712	3.85	3.66	22.72	45 253	416.6	4845	81.42	5.62
		2713	3.73	3.56	22.21	43 354	396.2	4604	82.59	5.87
		Average	3.83	3.63	22.95	45 002	418.1	4857	81.38	5.66
With Syphons	First	2716	3.45	3.26	24.72	40 283	214.7	5619	75.92	6.33
		2719	3.36	3.20	24.70	39 598	225.4	5898	75.00	6.42
		2724	3.40	3.23	24.84	39 868	210.0	5496	76.23	6.38
		Average	3.40	3.23	24.75	39 916	216.7	5671	75.72	6.38
	Second	*2715	3.04	2.86	20.99	35 854	285.8	4986	79.48	7.09
		*2717	3.03	2.86	20.73	35 806	224.3	3914	83.52	7.10
		*2720	2.98	2.84	21.92	36 016	308.7	5384	78.03	7.06
		2725	2.98	2.83	21.55	35 870	276.5	4823	79.93	7.09
		2728	3.13	2.95	22.58	37 438	309.5	5401	77.15	6.79
		2729	2.94	2.78	20.78	34 945	233.0	4065	83.05	7.28
		Average	3.02	2.85	21.43	35 988	273.0	4762	80.19	6.97
	Third	2722	3.11	2.94	21.33	36 689	292.9	5111	84.88	6.93
		2723	....	....	.....	.....	.....	....	.....	....
		*2727	2.91	2.75	20.38	34 862	237.9	4148	87.79	7.29
		2731	2.99	2.83	19.87	35 097	186.4	3245	90.32	7.25
		Average	3.00	2.84	20.53	35 549	239.1	4168	87.68	7.16
	Fourth	2718	3.71	3.52	23.40	43 607	450.0	5234	79.45	5.83
		2721	3.48	3.30	22.57	41 757	383.8	4467	82.69	6.09
		*2726	3.69	3.52	23.81	43 730	458.7	5334	78.88	5.82
		2730	3.66	3.47	23.47	44 227	446.6	5196	79.52	5.75
		Average	3.64	3.45	23.31	43 330	434.8	5058	80.14	5.87

*For the meaning of these asterisks see page 80.

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